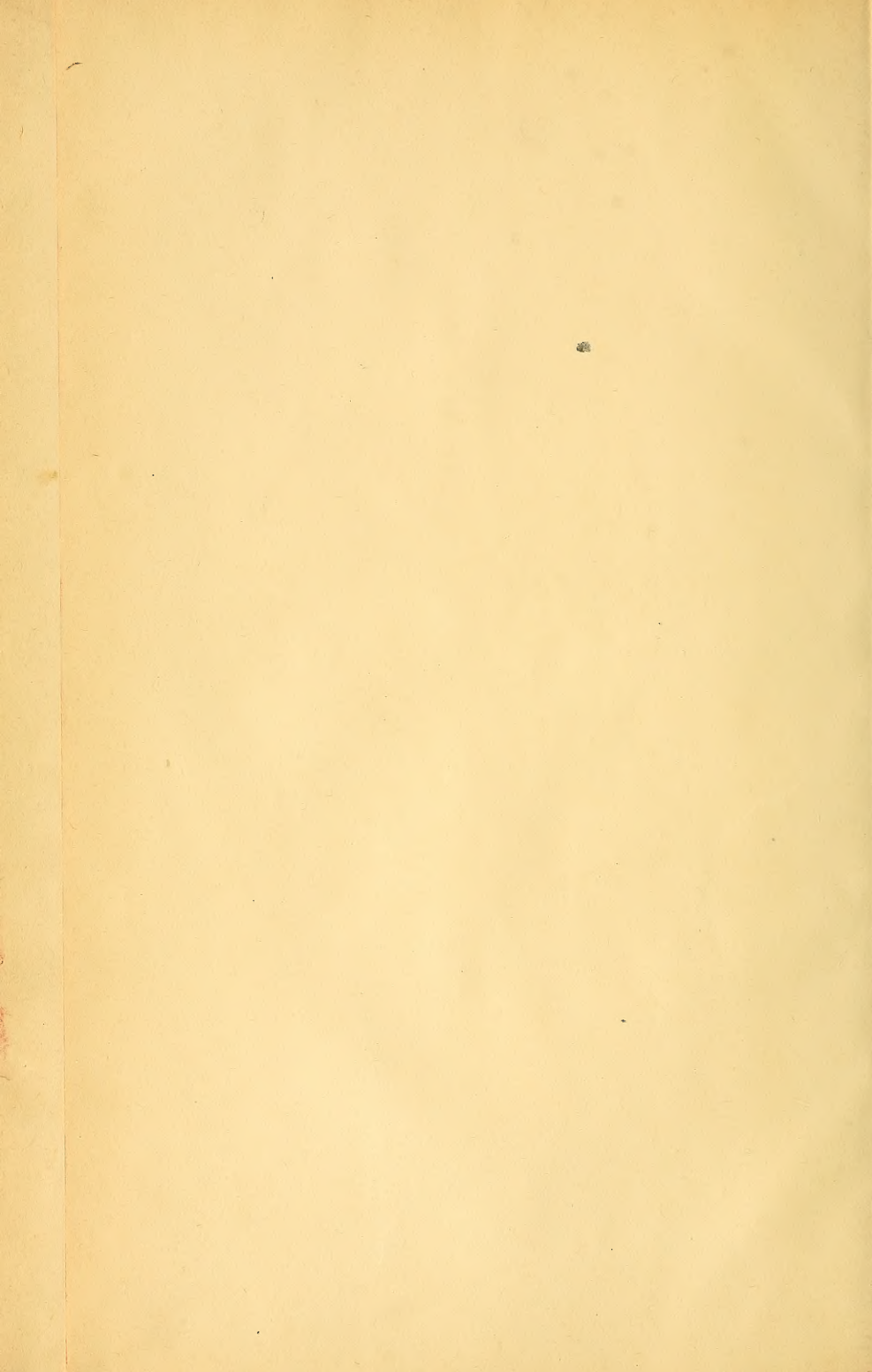
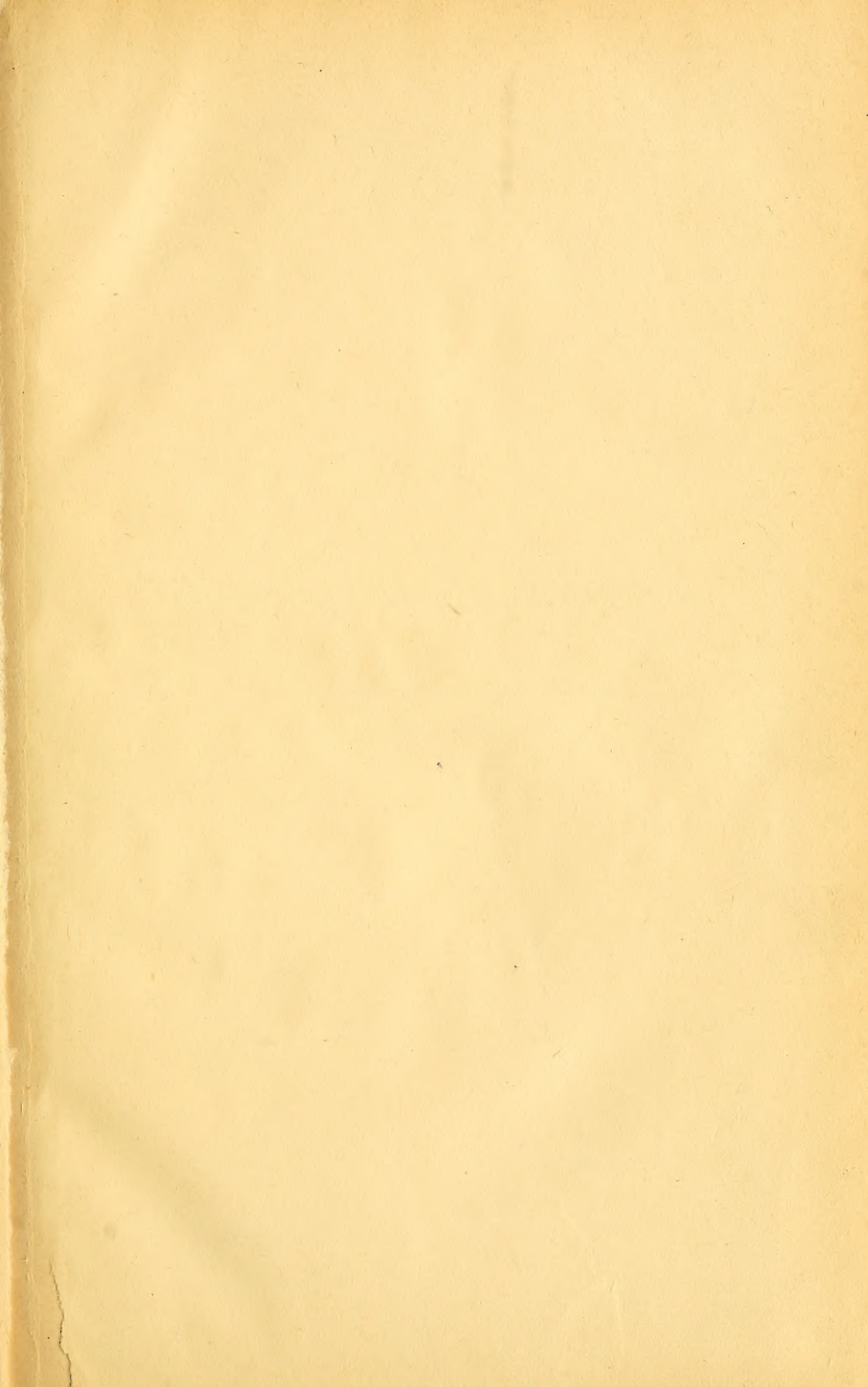
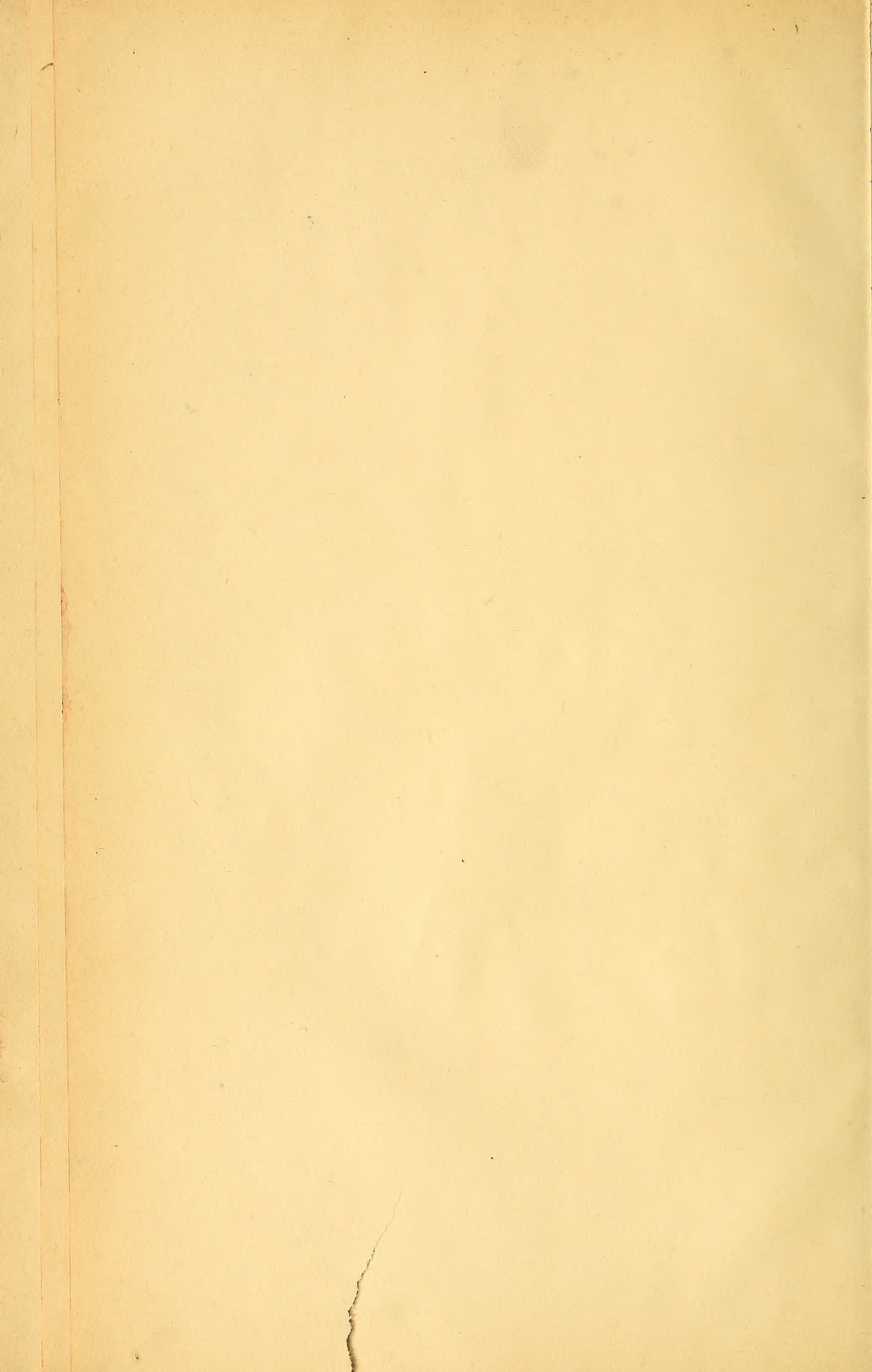












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JANUARY—DECEMBER, 1921.

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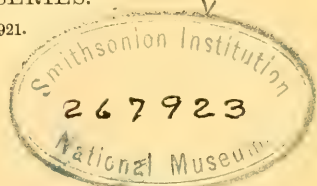
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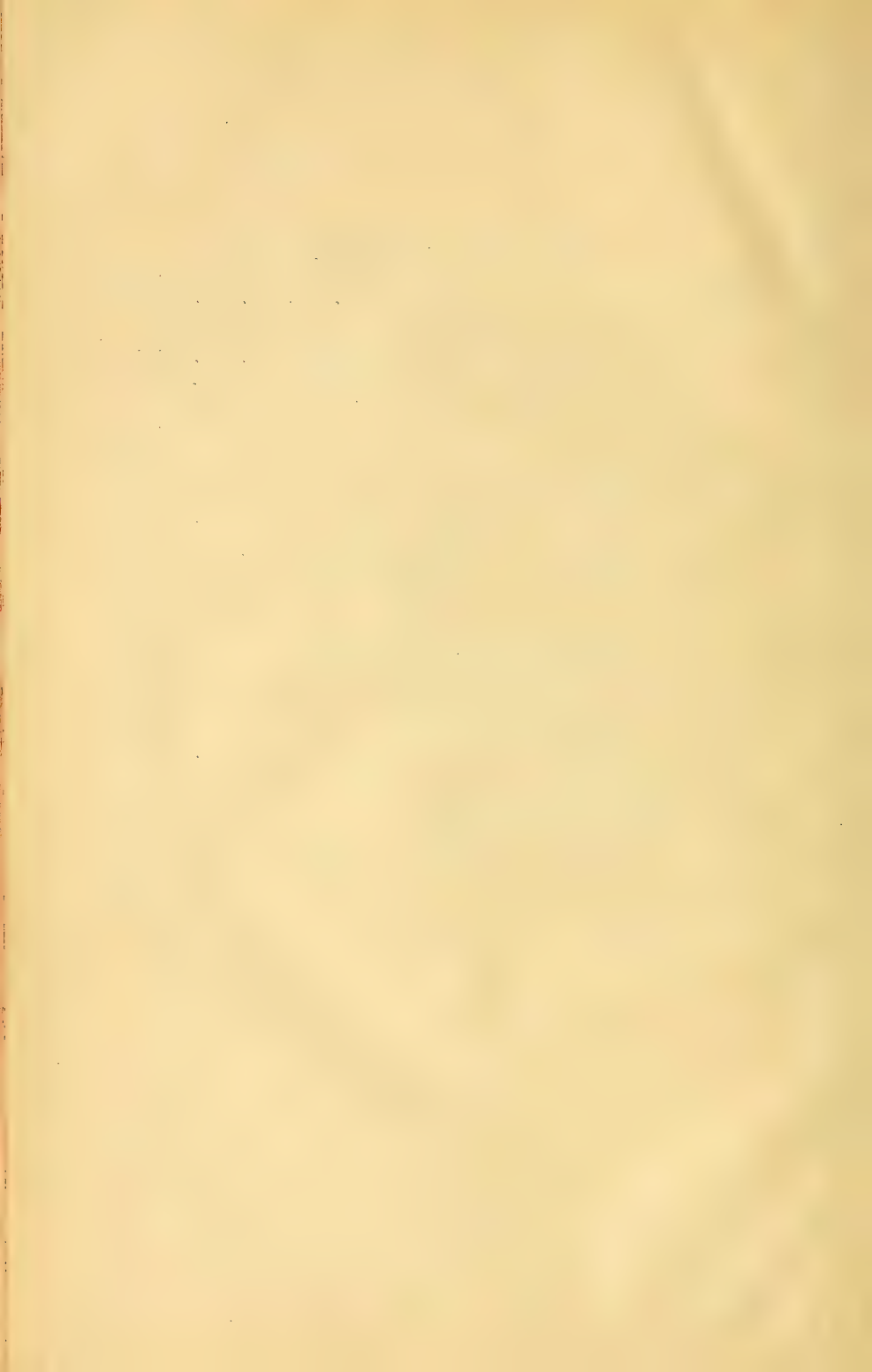
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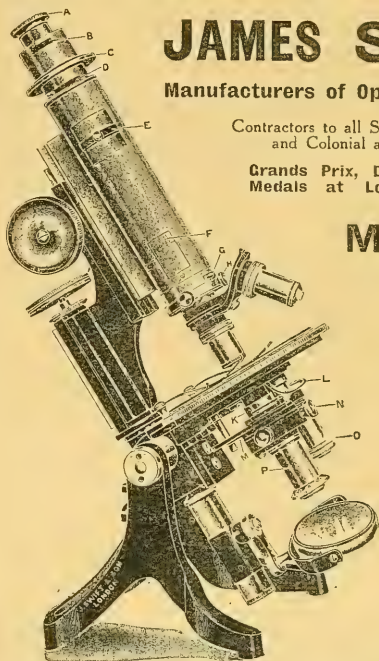
A. SMITH WOODWARD, LL.D., F.R.S.

JANUARY, 1921.

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OSWALD (FELIX), D.Sc., F.G.S. **A Geological Map of the Caucasus.** With explanatory text. Compiled from the latest sources. Scale 1: 1,000,000 (15·78 miles = 1 inch). 15s. The geological formations and the igneous rocks are clearly displayed in twenty different colours. The glaciers are also indicated. All heights are given in English feet, and the latest railways have been inserted. The pamphlet of explanatory text gives a brief account of the main physical divisions of the Caucasus, followed by a detailed description of the successive geological horizons with their characteristic fossils. Special care has been taken to indicate the exact position in the geological series at which petroleum occurs in the Caucasian oil-fields.

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THE GEOLOGICAL MAGAZINE

VOLUME LVIII.

No. I.—JANUARY, 1921.

EDITORIAL NOTES.

IN commencing a new volume the Editors desire to convey their thanks for the generous support they have received during the past year from contributors and subscribers. They still, however, find themselves faced with financial difficulties of a serious nature, arising from the continued increase in the cost of production. For the first half of 1920 a small profit was made, but this was almost wiped out by a considerable further rise in the cost of printing in the middle of the year. An important item in expenses is the cost of plates, and they are regretfully compelled to inform their contributors that it will under present conditions be impossible to produce plates at the expense of the Magazine. They feel sure, however, that their friends will not hesitate to incur the expense involved in meeting the cost of the illustrations, which are so necessary to bring out the full value of their papers. Many of them have done so voluntarily in the past, and the Editors trust that even under the present conditions, that bear so heavily on people of moderate means, they will be able to continue to provide them.

* * * * *

WHILE on this subject we should like also to take our readers and subscribers into our confidence and to inform them that although arrangements have been made which, at any rate, ensure continuance for 1921, there are limits to this sort of thing. In the first place it should be made quite clear that the Editors receive no remuneration, and are, as a matter of fact, slightly out of pocket as the result of their labours. Nevertheless, they do their work gladly in the interests of geological science, which they earnestly hope is really benefited by the continued existence of the Magazine, and they would feel the greatest regret if they were compelled by force of circumstances to relinquish their self-imposed labour of love. There are in hand at the present time a very large number of important papers awaiting publication, forming the firstfruits of the renewal of geological activity since the War; interest in many old problems has revived, and many new ones await solution. At the present time the prospects of our science are bright, and the Editors appeal earnestly to all its votaries to support them in their endeavours to further its progress. The Geological Society of America set an excellent example a year ago by guaranteeing forty new subscriptions to the Magazine, an act which has been the main factor making possible its continuance

during 1920, and it may be suggested that if each of our readers could obtain even one new subscriber the future of the Magazine would be assured.

* * * * *

WE have received a copy of the Annual Return made by order of the Trustees of the British Museum, showing the work performed by the Staff of the various departments, the visits made by the public, and the objects acquired by purchase and donation during the year 1919, with the income and expenditure for this great national institution, Bloomsbury, and its branch the Natural History Museum, Cromwell Road, South Kensington. The number of visitors to the Natural History collections during 1919 was 455,736.

* * * * *

GEOLOGISTS will be glad to learn that the collection of fossil corals and brachiopods from the Carboniferous Limestone of Britain and Belgium, made by the late Dr. Arthur Vaughan, has been secured for the Geological Department of the Museum. Owing to the wide distribution of our armies during the War, and of scattered British subjects in foreign lands, numerous additions have been made to the foreign collections of the Geological Department. Vertebrate remains have been presented from Afghanistan, Salonika, Egypt, the Sudan, Switzerland, Sinai, and California; and invertebrate fossils and plants from New Zealand, Australia, Arabia, Peru, Hanover, Canada, India, Persia, Ypres (Flanders), Malta, Taranto (Italy), Jamaica, Sardinia, the United States, Colorado, Dalecarlia (Sweden), Central Arabia, Esthonia, Samara, Russia, and Manchuria.

* * * * *

A GREAT work of national importance carried on in the Geological Department is Mr. C. Davies Sherborn's Index of the Genera and Species of Animals. During the past three years considerable progress has been made with this Index, under Mr. Sherborn's charge, and some 90,000 references have been added to the manuscript. The letter "T" of authors has now been reached. The manuscript has been continuously and extensively consulted by the staff and by students, whilst many inquiries have been answered by Mr. Sherborn in correspondence, which has been greatly increased owing to the many practical uses to which natural science is now applied, necessitating accurate nomenclature of the animals referred to. Further publication by Mr. Sherborn of bibliographic data has not been necessary during the past year; but a large draught has been made upon his manuscript by Mr. Gregory Mathews and Mr. Tom Iredale for their *Birds of Australia* and *Mollusca of Australia*.

ORIGINAL ARTICLES.

On the Geological Features of the Oil Region in the Northern Punjab (British India)

By H. PREISWERK, Basle.

(PLATE I.)

Introduction.

A. Rawalpindi Plateau (Potwár).

B. The Oil Region of Jaba in the Western Salt Range.

C. The Burning Gases of Jawalamukhi, Kangra District.

INTRODUCTION.

IN the great chains of mountains belonging to the Alpine system, stretching from the Armenian upland through Eastern Mesopotamia, Western and Southern Persia, and Baluchistan up to the Indus, then—in a great curve—encircling the Indian tableland in the Kirthar and Suleiman ranges and the Himalayas, then in the east turning south to Burma—there are several regions rich in oil, following the foot of the mountain-ranges on the border of the plains extending in front to the south. The most important of these oil-regions arrange themselves into three chief groups: the Mesopotamian-Persian region, the Baluchistan-Punjab region, and the Burmese region.

The Mesopotamian-Persian region and the Punjab region, summarily called by Sir T. H. Holland the "Iranian System", show a striking geological concordance in the occurrence of oil-shows. In both regions all oil-outcrops follow the border of large ranges of Eocene Nummulitic limestones, which both in Persia and in all oil-places in the Punjab that I have seen are overlain by variegated gypsiferous marls. Also the cellular limestone, which is so widely spread in the Punjab as a contact layer between the Nummulitic limestones and the gypsiferous clays, and which is probably of importance as an oil-bearing horizon, occurs again in the Persian oil-zones. As to the Persian oil-region, gypsiferous marls lying immediately over the Nummulitic limestones are considered to be the oil-bearers.

It is a striking coincidence that in the Punjab, too, the contact-zone between Nummulitic limestones and particoloured gypsiferous marls bears the oil-shows.

This stratigraphical horizon is also of eminent importance for the oil-bearing of the two regions. Its outcrop in the Punjab is shown on the sketch-map, Fig. 1. This also shows the chief oil-zones, from which we can clearly recognize that the oil-shows are strictly confined to the horizon just mentioned.

A. THE RAWALPINDI PLATEAU (Potwár).

The level plateau of Rawalpindi is limited by a steep range of Nummulitic limestone—8 miles north of the town. This range

stretches in a straight line from the Murree Mountains in the W.S.W. direction to the Margala Pass. Wynne calls the range the Margala Hills. They are the first range of the Hindukush. The Hindukush and the mountain ranges lying in front of it are composed of Archæan, Palæozoic, and Mesozoic formations. In the more southern ranges the younger formations predominate. In the most southerly range, the Margala Hills, we find Eocene Nummulitic limestone, which by its capacity for resistance forms a border range rising very



Fig. 1

suddenly out of the plain. The Eocene is not everywhere in its lower parts developed as Nummulitic limestone. Thus we find in the Trans-Indus district Eocene clays with gypsum and enormous masses of rock salt, below the Nummulitic limestones.¹ The Nummulitic limestones are partially bituminous, especially in their uppermost beds, which often consist of nodular limestones interbedded with clay. There, too, we find oil-shows.

¹ A. B. Wynne, Records of the Geol. Surv. of India, vol. x, p. 116.

Between the Nummulitic limestones at the base, and the immense sandstone beds following next above, there occurs with great regularity that very formation in which we find the oil-springs. It is called "Upper Nummulitic" by Wynne, and may be homotaxial with the "Kuldana beds" of Middlemiss.¹ It contains variegated, chiefly red or brown, clays and marls with gypsum and layers of porous or compact limestones and beds full of Nummulites and *Assilina*. Cellular limestones (cargneule) are often found at their base, forming the top of the compact Nummulitic limestone. In some parts these Upper Nummulitic beds have a thickness of several hundred metres.

The plateau of Rawalpindi (see Plate I) itself consists of red and gray sandstones, reddish clays, and conglomerates in the younger parts. These formations represent the middle and upper Tertiary: the Murree beds and the Siwalik group. We find them everywhere in the environs of Pindi, unless they are covered by the often thick conglomerates and loess-like formations of the diluvium and alluvium.

The separation between limestone hills on the one hand and the sandstone region of the plain on the other is not absolutely sharp: bands of sandstone occur also as synclines infolded with the limestones, such as the sandstone district of Sang-Jani, and also Nummulitic limestones rise as anticlines out of the sandstone region of the plain. Such "outliers" (Wynne) are e.g. the limestone hills north of Kutbal, which form the eastern branch of the Chitta Pahar range. They continue to the east as the anticline of Golra, which near Saidpur comes closer again to the Nummulitic limestone hills. At Golra and at other places in this advanced anticline the massive Nummulitic limestones of the antichinal core disappear below the variegated gypsiferous marls of the Upper Nummulitic. It is in these very places that the oil-springs appear. Precisely the same tectonic features give rise to the oil-springs of Gunda, near Fatehjang.

A yet more striking and isolated outlier is the Kairi-Murat ridge, south-west of Rawalpindi, where the Nummulitic limestone of the antichinal core rises out of the plain as a steep and long limestone ridge. At the east end of the ridge the Nummulitic limestone sinks in the axis of the anticline below the marls of the Upper Nummulitic, and these farther east below the sandstones of the Murree beds. Here, too, the oil appears above the Nummulitic limestone as soon as it is covered by the Upper Nummulitic clays.

All the Tertiary formations of the environs of Rawalpindi are intensely folded and squeezed together into tightly compressed folds. The dip is almost always very steep, and in the axes of the folds isoclinal structure is frequent. In the limestone ranges we find here and there overthrusts to the south. The sandstones of

¹ Memoirs Geol. Surv. of India, vol. xxvi, 1896, p. 42.

the plain are hardly less intensely folded than the limestone hills. But the sandstone folds have been almost wholly removed by erosion.

Taking into account the great thickness of the sandstones and the steep folding, we must suppose that the Nummulitic limestones and the oil-bearing beds covering them are mostly some miles below the surface in the plain about Rawalpindi. Places where they might be expected to exist at an attainable depth have up to this time not been found, excepting the east end of the Kairi-Murat ridge.

About 50 miles south of the Kairi-Murat ridge the Nummulitic limestones rise again from below the sandstones of the Murree beds, on the northern border of the Salt Range. It forms the north side of this long drawn-out range of mountains for more than a hundred miles, and still continues in the Trans-Indus extension of the Salt Range (see Fig. 1). In the eastern and central parts of the Salt Range no gypsiferous marls occur between the Nummulitic limestones and the overlying Murree sandstones. Only in the western part the marls appear again, together with cellular limestones (cargneule). And here, too, the oil-springs of Jaba appear, in the roof of the Nummulitic limestones, just as in the district of Rawalpindi and Fatehjang. In the same horizon south-east of Jaba a series of pitch occurrences is reported. We further have to mention the pitch-beds of Alagad, situated in the part of the Salt Range lying west of the Indus.

Further details of the stratigraphical development of the oil-horizon in the Salt Range are given later.

The structure of the western Salt Range differs from that of the ranges near Rawalpindi inasmuch as the folds of the Salt Range are less tightly compressed and more normally built, therefore showing on the average a smaller inclination of the strata.

In 1914 R. Zuber¹ published some notes referring partly to the same districts which I have examined. Zuber is of opinion that the different Nummulitic limestone ranges of the Potwár (outliers, Wynne) are thrust over the Murree beds, and now represent: "durch spätere Denudation zerrissene Ueberreste der Hazar-Decken." The same would be the case with the Salt Range, the strata of which are probably thrust over the Tertiary salt-formation. I do not want to discuss the new points of view Zuber has on the problem of the Salt Range, but only to put forward an opinion differing from Zuber's idea about the structure of the Nummulitic limestone ranges of the Potwár, especially of the Chitta Pahar and of the Kairi-Murat ridge, which I know more thoroughly. I certainly must agree with Zuber that at the south margin of the steep limestone hills of the Margala Hills overthrusts can be observed by which the Murree and Kuldana beds are overlain by the older

¹ Rudolf Zuber, "Beiträge zur Geologie des Punjab": Jahrbuch k.k. geol. Reichsanstalt, Wien, 1914, pp. 327-56.

Nummulitic limestones and perhaps also by Mesozoic limestones. A nice example of this is furnished by the limestone plateau projecting into the plain to the west of Saidpur, under the base of which sandstones and red clays of the younger formations disappear, while following the general strike of the range. I also know quite well that nice turn of the strata in the Nummulitic limestone (turning south) of the Kairi-Murat ridge which may be so well recognized from the Forest Bungalow of Murat. The only question is if those indications of north-south directed overthrusts have more than local importance, and if, on account of that, we are justified in considering mountain ranges like the Kairi-Murat ridge as remainders of an overthrust. I cannot answer this question in the affirmative. Wherever I had an opportunity of making exact observations, viz. in the eastern part of the Kairi-Murat ridge and in that part of the Chitta Pahar which runs out to Golra, I came to the conclusion that the Nummulitic limestone ranges of these outliers correspond to fold-axes of autochthonous anticlines. I, therefore, come back—contrary to Zuber's idea—to the view held by Wynne, who has expressed it not quite so distinctly in his sections, but very clearly on his map of the north-west Punjab.¹

The difference of opinion is best illustrated by comparing Zuber's sections: p. 338, figs. 2-5, and p. 343, fig. 9, with my sections IV-X, Plate I. The reasons which induced me to suppose autochthonous anticlines are:—

(a) The limestone ridges interrupting the uniform sandstone district of the Murree beds are not to be considered as erratic masses above the Murree beds, but as in stratigraphical normal connexion with them, the limestone core of the anticline being almost regularly accompanied on either side by variegated, often oil-bearing marls and clays of the Kuldana series (Upper Nummulitic) and separated by them from the younger Murree beds.

(b) The soft Kuldana beds would certainly not have remained in their normal position if forming the top of overthrust limestone-folds.

(c) Further, the massive beds of limestone of Sihala (Point 2207, Zuber, fig. 4) cannot be considered as an isolated overthrust relic. They form a member of an uninterrupted chain of several limestone outcrops, accompanied by Kuldana beds, which can be seen following in a straight line the strike-direction from Golra as far as Chitta Pahar, where they unite with the chief mass of the Nummulitic limestones (see Plate I). We can easily understand this range of limestone ridges as separate cores of a steep, compressed anticline; but we can hardly believe it to be the front boundary of an overthrust range.

The fact that the Kuldana beds frequently and often on both sides dip in under the limestone ridges is explained by the reflection that

¹ Map 1 inch = 8 miles, Records Geol. Surv. India, vol. x.

the soft Kuldana beds escape erosion and become visible especially where they are protected by swellings of the folded limestone core of the anticline (compare sketch Fig. 2).

DESCRIPTION OF THE OIL LOCALITIES.

1, Golra (Rawalpindi District). 2, Saidpur-Ratta Hotar. 3, Tret-Murree. 4, Fatehjang. 5, Sil and Basala Rivers, near Murat. 6, The Rock-Tar at Lundegar.

The six oil-fields I have visited belong to two Nummulitic limestone ranges:—

- (a) The border ranges north of the Rawalpindi plateau: Margala Hills and Chitta Pahar (Sections I–IV).
- (b) The Kairi-Murdi ridge, near Murat, south-west of Rawalpindi (Sections V and VI).

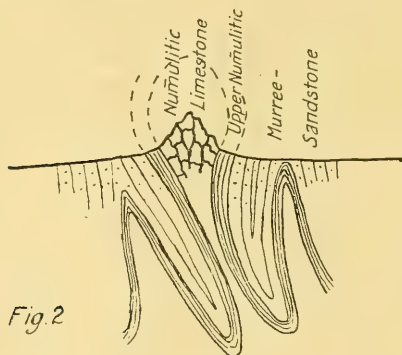


Fig. 2

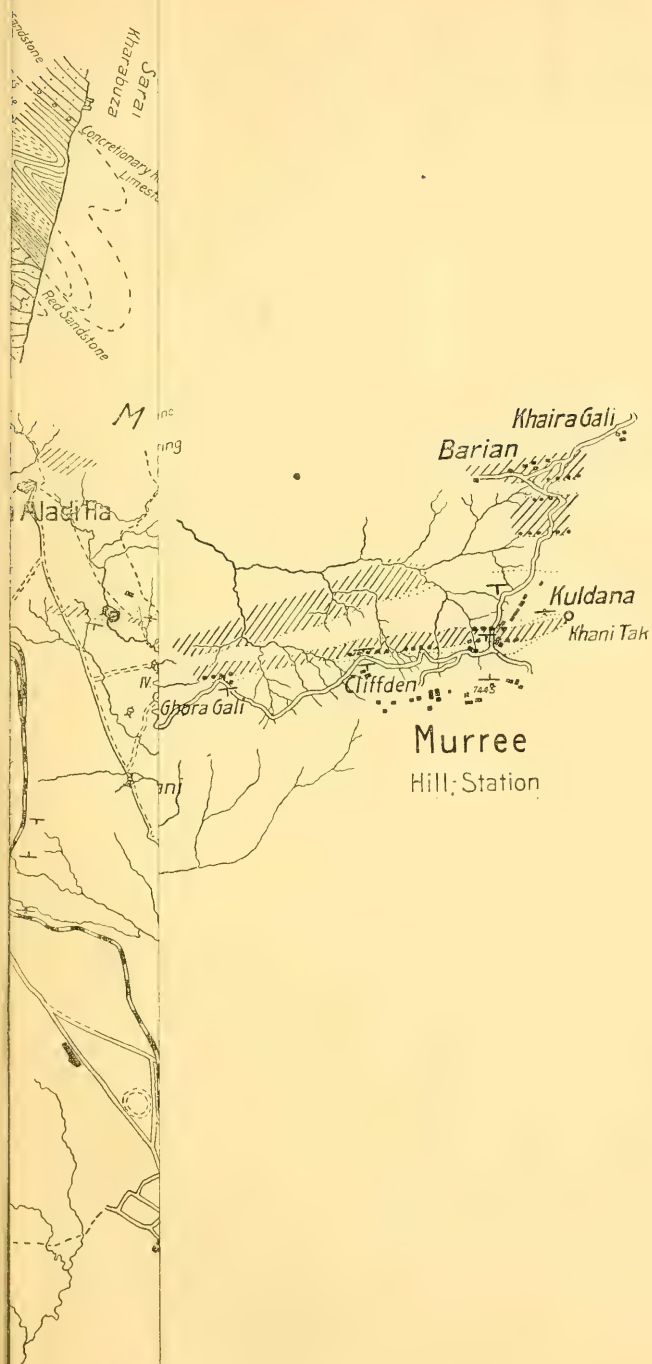
1. GOLRA.

The Oil-springs.

To the north and west of Golra we find three oil-springs, the most westerly of which is about 2 miles, the most easterly nearly 3 miles distant from the railway station of Golra Junction. The three oil-springs lie in a straight line, running N. 60° E., and there is a distance of something more than one mile between the most westerly and the most easterly of the springs (compare Plate I).

The most important of the three springs near Golra village is the one farthest to the east. It is situated on a small river, which has cut itself 4 metres deep into the plateau, about 400 metres to the north-east of the bathing-place, which lies in the garden of the Hindu Padri: Mamt Advita Nand.

The oil flows out in drops into the little brook, together with water containing sulphuretted hydrogen. The main spring rises a little above water-level on the western bank of the brook. In a dark-brown substance mixed with clayey and tarry material there is an excavation which is filled with oil, and—when exhausted—fills itself again daily. The oil is somewhat thick and of a dark-brown colour.





I have been told at the Rawalpindi gas-works that they yearly obtained about six barrels of oil from Golra. Together with other oil and wood it is used in the manufacture of gas and of tar.

The second oil-spring, hardly 100 metres farther to the west, lies in the bed of a brook parallel to the first. There, too, we notice in various places oil flowing into the water of the brook together with springs of sulphuretted hydrogen. The main oil-spring is only a few feet above the brook in a little channel running east. It is a cavity filled with oil. From time to time gas-bubbles rise from the oil.

The third and most westerly oil-spring is situated near the Mosque of Dheri Shah Sikandar Wali. To the east of this building, on the left bank of the river, appear limestones with clayey marls richly impregnated with oil.

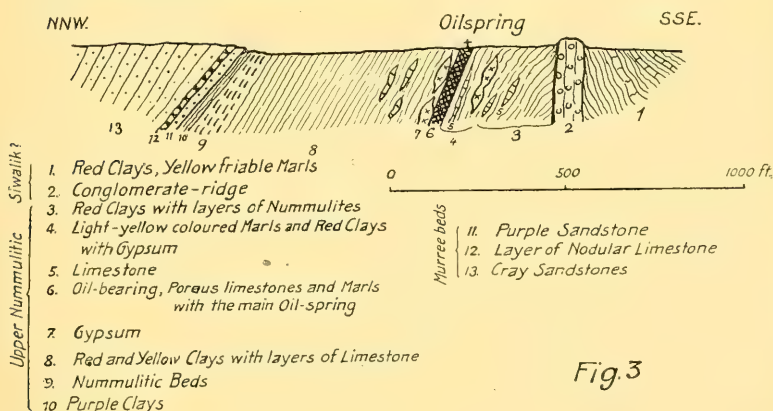


Fig. 3

Some oil is also said to flow out of a channel halfway between the main oil-springs of Golra and of the Mosque. There was, however, nothing to be seen at the time of my visit.

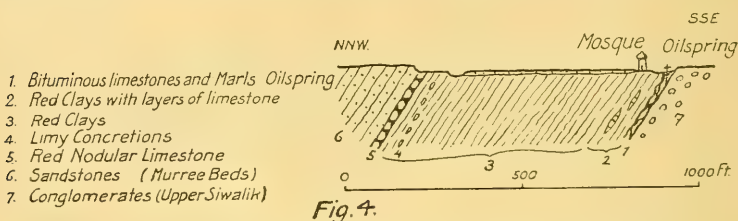
Geological Structure of the Neighbourhood of the Oil-springs.

1. *Near the Oil-springs.*—The section (Fig. 3) informs us about the nature and arrangement of the rocks in the immediate neighbourhood of the main oil-springs north of Golra.

Many of the rocks appearing near the main spring on the brook are very bituminous, and the thickness of the bituminous beds may be estimated at 40 feet.

The oil-bearing rocks are essentially porous and crumbly limestones and calcareous marls as well as gypsum. Here and there we find beautiful crystals of aragonite in the oil-marls. The strata have an inclination of 60° on an average, towards N.N.W. Towards the lower end of the valley, below the oil-bearing beds, follow red and light yellow coloured marls and clays, about 50 m. thick,

with layers of compact limestone and gypsum and limy beds rich in Nummulites. The strata, which dip north, show lower angles of inclination, down to 35° towards the south. Near the end of the valley these clays sharply break up on the perpendicular strata of a conglomeratic ridge (compare Fig. 3). The conglomerates chiefly consist of large boulders of grey and yellow limestone. These conglomerates might belong to the Upper Siwalik formation. To the south of the ridge very steep clays and marls follow, quite different from those near the oil-springs. Farther away from the ridge the strata quickly become more level, and disappear below the alluvium. Thus the environs of the conglomeratic ridge appear as the axis of an anticline, the crest of which shows an important dislocation.



Turning to the north from the oil-beds to the hanging-beds, we first meet red and yellow clays with lenses of Nummulitic limestone and gypsum. The clays are more than 100 metres thick, and similar to those below the oil-bearing rocks. They are irregularly disposed, in certain parts steeper, in others more level. About 200 metres to the north of the oil-shows a hard and ridge-like purple sandstone crosses the bed of the river. Purple clay and yellow nummulitic layers, which are extremely rich in fossils, appear below the sandstone, representing the uppermost part of the nummulitic formation. The purple sandstone of the boundary dips north at 45° . It is covered by a bed of characteristic red nodular limestone. Such nodular limestones are often significant for the boundary between the Upper Nummulitic and the Murree beds. Farther to the north we notice now the monotonous sandstones of the Murree beds.

The section through the oil-spring near the Mosque Dheri Shah Sikandar Wali is represented on Fig. 4. The conditions here are similar to those of the main spring to the east. There, too, the oil flows out from layers of limestone in the variegated clays, which also here—in a distance of 200 metres from the oil-beds—are covered by the sandstones of the Murree beds. The sandstones dip rather more steeply than on the east, perhaps 60° , whilst the clays have only an inclination to the north of 50° . The southern part of the section is only exposed to a small extent. The variegated clays with their layers of limestone and the oil-springs are cut off in the south from the coarse conglomerates on the river near the

Mosque. These conglomerates are very similar to those in the ridge near the eastern main oil-spring.

From what we have seen so far *the three oil-springs near Golra have the same geological situation*. They all appear in the lower parts of the variegated clays. These variegated, nummulitic, and gypsum-bearing clays—according to Wynne belonging to the “Upper Nummulitic”—can be traced for more than a mile distance near the oil-springs of Golra, with a breadth of 300 metres. They dip to the north at about 60° . In the middle, between the eastern and western springs, however, nearly vertical bedding is found. Here, near the graves of the Mohammedans on the hill, they are pierced by a larger mass of limestone (Plate I).

2. *On the Surroundings of Golra*.—We acquire a general knowledge of the geological structure by tracing the section through the main springs in the north of Golra farther north (Section IV, Plate I). From the first appearance of the sandstones we meet—for a whole mile, as far as the foot of the steep limestone hills—nothing else but sandstones with scanty beds of clay, the strata mostly dipping very steeply. At the foot of the first hill of the mountains the sandstone, however, forms a syncline which is more flat, and afterwards the red clays of the “Upper Nummulitic” appear, and still more to the north the enormous masses of the “Hill-Nummulitic limestone” with still older—according to Wynne—Mesozoic limestones in perpendicular strata or even turned over the “Upper Nummulitic” by inversion.

The Section IV (Plate I) tries to explain the tectonic conditions of the four formations: the Nummulitic Limestone, the Upper Nummulitic, the Murree Sandstone, and the later (Siwalik) conglomerates and marls. According to this section there are, between Golra and the top of the limestone hills, two anticlines, the core of which is formed by Nummulitic limestones. In the northern anticline the limestone itself appears, forming the mountain range, whilst in the southern anticline it is hidden, at least near the oil-springs, below the Upper Nummulitic. The Upper Nummulitic appears in the northern anticline as a reduced and overturned south flank, in the southern anticline as a normal north flank. But towards the south it does not continue below the normal hanging Murree beds, but is cut off from the younger conglomerates by unconformity. From this we see that an important dislocation runs in the direction of the axis of the anticline, which has lowered the south flank, or rather, has overturned the north flank over the south flank. The Murree beds form a proper syncline, which, however, is very unsymmetrically built, its axis being displaced to the north. The flank of the syncline, which is turned towards the mountains, must therefore be either completely crushed or covered by the overturned and anticlinal Hill-Nummulitic limestones.

To the south of the line of dislocation, near the oil-springs,

no Murree sandstones appear, but only younger conglomerates and marls, which might belong to the Upper Siwalik or even to the older Diluvium. The absence of the thick Murree formation shows that we have to deal with a very remarkable dislocation, which I have looked upon as a fracture and steep overthrust of the crest of the anticline.

Owing to the steep dip of the Siwalik conglomerates we must conclude that the folding of the rocks has been going on up to the youngest geological periods.

I have further examined the formations running west and east from the section of the Golra oil-spring. First the anticline of Golra : The anticlinal axis is soon covered by alluvium to the east of the main oil-springs. About half a mile to the east outcrops show again, near Hill 2207 (Section V, Plate I). This hill has already been mentioned on p. 7. Here the anticline is strongly pushed up. The massive Nummulitic limestones, which form the core of the anticline, appear on the steep Hill 2207, running along the crest, accompanied on both sides by the overlying Upper Nummulitic and the Murree beds. The Upper Nummulitic is here completely eroded away on the anticlinal axis. The strata are everywhere very steep. The south flank is overturned, and dips north at 60°. The limestones in the axis of the anticline are covered by alluvium towards the east of Dheri Kila, and only appear again near Saidpur and Nurpur Shahan.

The anticline of Golra is hardly exposed to the west of the Mosque Dheri Shah Sikandar Wali. Some isolated exposures of variegated marls and a limestone ridge, that crosses the road from Rawalpindi to Shah Aladitta, mark its course. About 3 miles to the west of the oil-springs—between Sarai Kharabuza and Johd—the Upper Nummulitic is again well exposed as grey-black, fossiliferous, and variegated clays of a thickness of several hundred metres. Adjoining them towards the south appears the Nummulitic limestone, which crosses the road from Rawalpindi to Sang Jani as a ridge. The limestones break forth always more towards the west. They form the hills to the south of Sang Jani, accompanied on both sides by younger formations, and continue their course in the limestone hills of the Kala Chitta Reserve to the north of Kutbal. While the Golra anticline runs W.S.W., the southern border of the Margala Hills, to the north of Golra, runs directly west. Thus the sandstone-syncline between the two anticlines to the west widens out considerably, and reaches a breadth of about 4 miles in the neighbourhood of Sang Jani. Toward the east, on the contrary, this syncline of Sang Jani—Shah Aladitta becomes rapidly narrower. The sandstones forming the core of the syncline appear in the environs of Saidpur only in scanty patches embedded in the Upper Nummulitic, which, still farther east, at last as a narrow stripe, separates the limestones of the Golra anticline from the Hill-Nummulitic limestones of the principal anticline, both of which join to form one mountain mass to the east of Saidpur (see Plate I).

The occurrence of oil is therefore closely related to special geological features. It occurs only in the boundary region between the Hill-Nummulitic limestone and the Upper Nummulitic (Kuldana beds). It appears on the surface only where the beds have a normal position and a moderate inclination (below 60°). This is especially the case in places where the Nummulitic limestone dips axially under a closed cover of clays and marls of the Upper Nummulitic.

The oil-bearing bed is chiefly cavernous, marly limestone, and partly gypsiferous marls.

2. SAIDPUR-RATTA HOTAR.

Oil-springs.

The oil-spring of Ratta Hotar is situated $\frac{2}{3}$ mile north-west of the end of the Tonga Road from Rawalpindi to Nurpur Shahan, and a few hundred yards east of the park and the graves, where a Mohammedan priest resides. On the topographical map (1 inch = 1 mile) the place is marked by the name "Gugul pani". Along a little channel there are outcrops of a disturbed limestone mingled with oil-bearing marls 20-30 yards long and a few yards broad.

At the spring itself there is a hole from which water issues covered with thick oil. The oil flows drop by drop. The flow of the oil is said to be somewhat stronger in the dry season.

Geological Features.

The Section Ratta Hotar.—Section VI, Plate I, shows the geological situation of the oil-spring at Ratta Hotar.

The oil-bearing rock: the limestone lenses with interstratified clayey marls form the contact-layers between the compact Nummulitic limestones and the gypsiferous variegated clays of the "Upper Nummulitic". These lenticular limestones are also found elsewhere in the upper parts of the Nummulitic limestone. They are widely developed near Murree, and there also they are bituminous for long distances. I have found them again in typical development in the Eastern Salt Range between the Nummulitic limestones and the Murree sandstones, but there they were free from bitumen. A few metres south of the oil-springs the massive Nummulitic limestone is exposed, forming a steep ridge and dipping north at 70-80°.

To the north of the oil-rocks follow the typical variegated gypsiferous clays of the Upper Nummulitic. These dip north a little less steeply (about 65°).

To the east of the oil-springs sandstones appear between the oil-rock and the marls. They are also represented in Section VI, Plate I, although they are not visible at the oil-spring itself. I suppose these sandstones to form a synclinal core of Murree beds.

By the outcrops in Section VI of Rattar Hotar the existence of two anticlines with two corresponding synclines is proved.

The anticlinal cores consist of Nummulitic limestones, the

synclines of gypsiferous marls of the "Upper Nummulitic" and sandstones of the Murree beds.

The geological features of this section correspond to those of the Golra section. The southern anticline of Ratta Hotar is the direct eastern continuation of the oil anticline of Golra, as shown on the geological map (Plate I). The syncline between the two anticlines in Section VI is the continuation of the syncline of Sang Jani and Shah Aladitta. The Murree sandstones of this syncline, which north of Golra have a breadth of more than one mile, are reduced to a minimum at Ratta Hotar.

Environs of Saidpur.—The syncline with Upper Nummulitic clays north of the oil-springs of Ratta Hotar can be followed up to the west as far as Saidpur. It is always accompanied, on both sides, by limestones. To the west of Saidpur the variegated clays with gypsum appear in isolated complexes only, disposed in a way which leads us to suppose that overfolding of the northern anticlinal limestone core over the syncline has taken place. In the village of Saidpur, even at a place where oil is said to be found, nothing is to be seen of the variegated clays, which otherwise always accompany the oil; only limestone appears. The red clays are, however, visible immediately east of the village, and dip north at only 40°. It is probable that at Saidpur the clays are covered by overfolded limestones. North of the village we notice in the limestones planes of overthrust dipping north at 40°.

The bituminous rocks of Dhak Jiwan lie exactly in the line of the syncline Ratta Hotar-Saidpur. Thus it is most probable that this oil-bearing zone continues in depth below the limestone masses to the west of Saidpur.

Occurrence of the Oil.—Oil and oil-bearing rocks appear in the environs of Ratta Hotar especially in the transition beds between Nummulitic limestones and the younger gypsum-bearing clays of the "Upper Nummulitic". In some places oil-traces are said to occur also deeper in the Nummulitic limestones. As the rocks possess very differing qualities above and below the oil-zone, the oil-lines are easy to recognize. The limestone bed running from the village of Saidpur eastwards to Ratta Hotar and crossing, about 1 mile north of the village of Mandla, the side-valley of Bharakao contains the most important oil-shows on its boundary-lines on both sides towards the Upper Nummulitic. This limestone region is, indeed, the core of the anticline of Golra. Thus we find also in the Saidpur region the most important oil-spring, that of Ratta Hotar, on the north flank of the Golra anticline.

3. TRET-MURREE (Plate I, Sections VIII, IX).

The north-eastern continuation of the oil-zones of Golra and Saidpur-Ratta Hotar is well exposed on the high road from Rawalpindi to Murree, between Tret and Murree, and also on the

hill road from Murree to Kuldana and Khaira Gali. The observations made in this region I have entered on Plate I. The road from Rawalpindi to Murree runs from its entrance into the hills almost, exclusively in the sandstones of the Murree formation. Below Tret, however, where the road sharply curves to the north-west round the isolated hill, and where the footpath to Tret branches off, the road cuts red clays, then greyish-yellow lenticular or nodular marly limestones, and finally massive Nummulitic limestones, somewhat crushed. On the north side of the hill nodular marly limestones appear again and also the sandstone. Evidently we have to deal here with a tightly pressed anticline, in the core of which Hill-Nummulitic limestones appear. It is strange that the hanging layers dip, on both sides, steeply towards the anticlinal limestone core. The nodular marly limestone corresponds stratigraphically to the oil-rocks of Ratta Hotar, and indeed here,

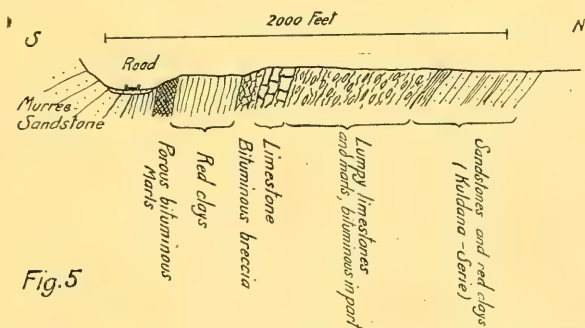


Fig. 5

too, it is bituminous, as can be seen from the exposures on the north side of the hill near the bungalow of Tret. I have followed up this anticline for many miles to the north-east as far as a little village, Khani Tak, in the steep forest ravine north of Murree (Plate I). There the limestones disappear among the sandstone masses, and the anticlinal core dives below the hanging beds. In the axis of the anticline the strata are standing almost perpendicular, more moderate inclinations occurring, however, in the south-east slope, e.g. near Charra Pani. The Murree sandstones in the south-east flank throughout show a moderate inclination (50° – 20° south-east). The anticline is very rich in bituminous rocks from Tret onwards to its east end. These appear especially in the zone between Nummulitic limestones and the red gypsum marls of the Upper Nummulitic or, where this is missing, between limestone and Murree sandstones. They appear, however, also in the limestone mass itself or in limy-marly porous rocks of the Upper Nummulitic. They therefore seem stratigraphically equivalent to the oil occurrences at Golra and Saidpur.

The Upper Nummulitic can easily be examined, especially in the south flank of the anticline, the road to Murree cutting this formation

in nearly all its northern curves: at Ghora Gali, at Basra Gali, at Tschita Moor, at Sunny Bank, and where the road branches off to Kuldana. North of the Kuldana cross-road the road to Kuldana cuts the section Fig. 5.

The bituminous limestones are quarried and furnish good gravelling material. It is worthy of note that the massy Nummulitic limestones are less developed in this section, the nodular marly limestone, which forms the upper beds of the Nummulitic limestone series, predominating. This fact may, tectonically, be explained, in that the core of the anticline is sinking rapidly here, towards the east below and between the overlying Murree sandstones, as shown by the exposures near Khani Tak (Plate I).

The north flank of the anticline contains here also bituminous beds. Bituminous rocks are probably to be found along the whole length of the north flank, which is here less easily accessible than the south flank. I have examined this north flank in the deep gorge of the Kurang River. Sections VIII and IX of Plate I show the geological features stated there. The northern contact of the anticlinal limestones show throughout bituminous rocks. They are the same nodular limestones carrying bitumen as we have found at Kuldana. It is also the same bituminous zone struck by the Tret road. At the bottom of Kurang valley the bituminous rocks are accompanied by several sulphur springs; 7 or 8 miles to the north-east, at the end of the limestone range at Khani Tak, another sulphur spring comes forth, which also illustrates the geological conformity of the whole range from Tret to the east of Kuldana.

To the north of the section represented on p. 15 follow the sandstones of Kuldana, which I take to be a syncline between the anticlinal limestones. These sandstones are again followed, to the north, by thick red clays of the Upper Nummulitic, and then at Dara Gali, by a Nummulitic limestone anticline also containing bituminous beds.

This section has already been described by Wynne and later by Middlemiss.¹ His section stretches north as far as the Nummulitic limestone of Dara Gali. There seems to be a great probability of these northern Nummulitic limestone zones of Dara Gali being identical with the Golra anticline. The narrow anticline of Tret must then correspond to the pre-anticline of Mandla. From this fact we see the bituminous zones of Golra-Saidpur-Ratta Hotar extend very far towards the east, and it seems that most of the bitumen is found in those anticlines which are farthest advanced towards the sandstone foreland.

Some samples of the bituminous marls of Basra Gali and Ghora Gali gave 7-9 per cent bitumen (as benzol extract).

4. FATEHJANG.

A certain number of natural and artificial oil-shows are to be found some miles north-west of the little town of Fatehjang. Near the

¹ *Memoirs Geol. Surv. India*, vol. xxvi, p. 225.

village of Gundewali Bani (Gunda) there is a pit about 50 feet deep and a boring 75 feet deep, as well as several small shafts, from which oil is obtained occasionally.

Further details are to be found as follows :—

Wynne: "Note on the Petroleum Locality of Judkal, near Futtijung, west of Rawalpindi, etc." (Records Geol. Survey of India, vol. III, 1868, p. 73).

Lyman: *General Report on the Punjab Oil Lands* (Lahore, 1870).

The boring struck Nummulitic beds rich in fossils and cellular limestones.

About two miles west of Gunda, at the southern affluent of the Bhagwan Kas, oil-traces are to be found in gypsiferous green marls, and at the Bhagwan Kas itself we also find nice oil-outcrops in marly layers between limestones dipping steeply north.

Near the village of Charat there are also oil-outcrops as well as a boring 15 feet deep, out of which gas and oil escape. Oil-springs also appear in a little anticline west of Charat (about 1 mile).

The numerous oil-outcrops are also here restricted to the base of the Kuldana beds, which together with Nummulitic limestones rise in the shape of a steep anticline from under the Murree beds.

From the map and the sections I-II, Plate I, we see that we have here to deal with a complex anticline, the structure of which rapidly changes along the strike. The various cores of the subsidiary anticlines (consisting of marls and limestone) are separated from one another by distinct sandstone synclines; this can be seen very clearly at Gunda.

The whole complex of the Nummulitic limestones and the Kuldana beds near Fatehjang form an isolated anticlinal zone lying parallel to the front of the Chitta Pahar chief anticline, just as the anticline of Golra is related to the chief anticlinal zone of Margala.

Compared with the Golra region, that of Fatehjang shows on an average a less considerable dip of the strata, which is worth mentioning in regard to the oil occurrences.

The facies of the Kuldana beds (Upper Nummulitic) near Fatehjang is deviating from the development near Golra in so far as in the anticline of Fatehjang the clay—and marl—facies of the Kuldana beds extend into the underlying Nummulitic limestone as well as into the overlying Murree sandstone formation.

I wish to point out especially the considerable abundance of fossils in the clayey marls overlying immediately the Nummulitic limestones and the cellular dolomites. The exposures of these marls attract our attention by an enormous number of isolated individuals of *Assilina*. According to Zuber, *Assilina exponens* and *Nummulites perforatus* are especially abundant (loc. cit., p. 342).¹

Near Charat I have found pieces of a big tooth in the "Upper Nummulitic" (Kuldana beds). Dr. H. Stehlin, of Basle, succeeded

¹ Wynne also mentions "teeth of sharks" and "large bones": Records, III, p. 73.

in reconstructing it. He was kind enough to tell me that we have to deal here with one of the two last premolars of a large Perissodactyle, which does not seem to belong to any of the genera known up to the present.

Section across the Oil Anticline at the Sil and Basala-confluence

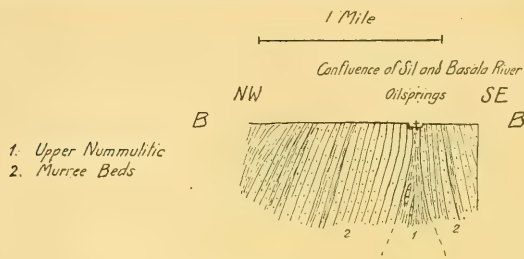


FIG. 6a.

Special section across the oil bearing beds at the confluence of Sil River and Basala River near Murat

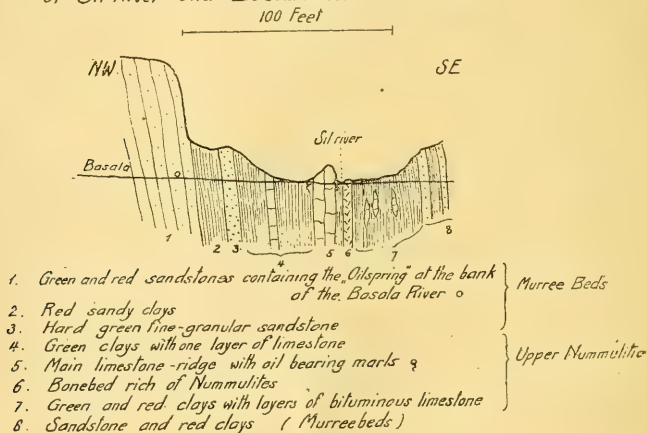


FIG. 6b.

5. SIL RIVER AND BASALA RIVER, NEAR MURAT.

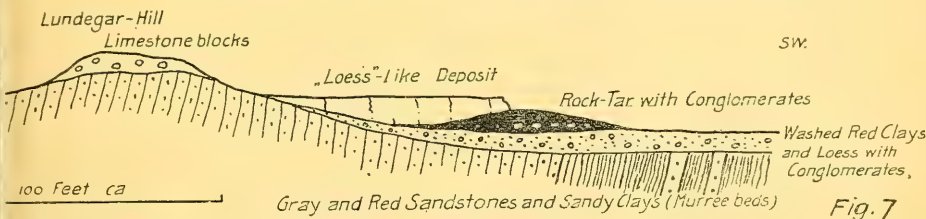
The Oil-springs.—The place where the oil is found is at the confluence of the Sil and Basala, $1\frac{3}{4}$ miles east of Murat, which lies at the east end of the steep limestone range of the Kairi-Murat ridge. The distance from Rawalpindi is about 10 miles. Cart tracks lead over the flat country as far as 2 miles east of the oil-place, which is reached by a camel track crossing the steep canyon of the river, which is about 20 m. deep.

At the time of my visit (beginning of August) the river was rather high, and nothing could be seen of the oil-outflow. I was able, however, to determine the existence of calcareous marls richly impregnated with oil. I noticed them in the crevasses and flanks of the limestone ridge right in the Sil River.

B. S. Lyman¹ says of these oil-springs:—

“The oil rises up through the extremely shallow water of the river; one drop at a time every minute or two gives rainbow colours to the surface of the river for the space of a few inches, then floats away and disappears. At a distance of about 20 yards north-easterly, apparently on the outcrop of the same bed of shales, is another like show of oil; also at one or two other places between these extremes.”

The oil-springs of the Sil and Basala Rivers are important on account of their geological situation. The rocks accompanying them are represented in Fig. 6b. These rocks are typical representatives of the “Upper Nummulitic”, which forms here a narrow zone (running N. 60° E.) between the sandstones of the Murree beds. The character of the oil formation is here entirely similar



to that of Golra and Saidpur. Bituminous limestones and marls are found along the strike of the beds on both sides of the oil-springs: to the west of the river in a steep channel in the plateau-margin about 30 m. above the river, to the east about 120 m. distant from the oil-springs, also in a narrow gorge in the steep slope.

Farther east on the plateau, the “Upper Nummulitic” can still be identified by the appearance of limestone lenticles (for the length of about half a mile). Farther on to the east only sandstones of the Murree beds are exposed.

Near the oil-springs, as shown by the sections, almost vertical bedding is found, and to the south and north there follow thick masses of also very steep Murree sandstone, which dip only a little less steeply north and south at a considerable distance from the springs, thus allowing us to recognize the anticlinal structure of the oilfield (Fig. 6a).

We can follow the anticlinal core to the east for not quite a mile in the sandstone; farther east isoclinal stratification predominates,

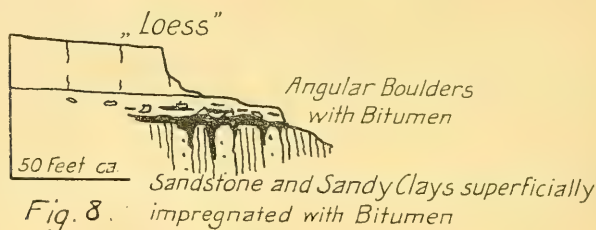
¹ B. S. Lyman, *General Report on the Punjab Oil Lands*, Government Press, Lahore, 1870.

and alluvium covers the plain and prevents us from recognizing the structure of the Tertiary strata any farther.

On the plain to the west of the Basala River exposures are very rare. It is only at Murat, in the brook encircling the place, that the strata of the Upper Nummulitic are very nicely exposed. In the little valley, which branches off north from the eastern curve of the brook, outcrops of bituminous limestones occur.

To the west of the village the steep Nummulitic limestone masses of the Kairi-Murat ridge rise from the plain. The Upper Nummulitic and the Murree sandstones accompany the limestones at the foot of the mountains south and north of the ridge in steep or often overturned strata.

The village of Murat, therefore, lies at the very place where the massive Nummulitic limestones disappear to the east below the Upper Nummulitic beds.



It is worthy of note that the bituminous character of the rocks is pronounced just at those places where the limestone anticline dives below. The axis of the anticline is, to the east, marked only by the Upper Nummulitic, while the massive limestones have definitely sunk below.

It is peculiar that the connecting link between the anticlinal core at Murat and the anticline at the oil-springs does not agree in its direction either with the general direction of the Kairi-Murdi ridge nor with the strike of the strata at the Sil and Basala Rivers. The anticlinal axis must, therefore, have suffered either a strong bend to the south between Murat and the Basala River or a displacement to the south along a tranverse fracture.

6. THE OCCURRENCE OF ROCK-TAR NEAR LUNDEGAR.

About $2\frac{1}{2}$ miles south-west of Murat, near Dhak Bhatwari, a hill called Lundegar rises out of the gently north-west-rising surface of the country. The hill consists of limestone boulders, at the base of which sandstones of the Murree formation are exposed with steep dip (Fig. 7).

About 100 metres south-west from the hill a flat lenticular mass of tar appears from under a cover of loess, with an extension of about 15 metres. In a brook near by, the base of the tar-lens is denuded. It consists of mixed clays, loess, and conglomerates.

Here and there steep sandstones and clays of the Murree beds are exposed below them.

About 200 metres farther west the steep Murree beds are again visibly covered by boulders and loess. At the base of the alluvial deposits bitumen appears. Also the strata of the Murree beds are in some parts impregnated with it (*vide* Fig. 8).

No doubt the tar is lying in a secondary position, and in all probability originates in the Upper Nummulitic that is exposed at the foot of the limestone ridge of Kairi-Murat (comp. Section X, Plate I).

The tar occurrence of Lundegar is a further proof of the great extension of oil and bitumen in the Upper Nummulitic.

(*To be continued.*)

The Interglacial Problem and the Glacial and Post-glacial Sequence in Northumberland and Durham.

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SINCE my papers on "The Superficial Deposits and Preglacial Valleys of the Northumberland and Durham Coalfield"¹ and "The Origin and Influence of the chief Physical Features of Northumberland and Durham"² were published, a great deal of detailed work has been done on the glacial phenomena in the two north-eastern counties by Smythe,³ Merrick,⁴ Herdman,⁵ Trechmann,⁶ and myself.⁷ As I have given much attention to this subject it may be of interest and value if I give a brief resumé of my views, a general summary of the work done, and attempt to show the general sequence of the phenomena that have been described. My extensive study of the Drift in these two countries and elsewhere has convinced me of its complexity. I cannot, therefore, be dogmatic on any points, but will endeavour to show the general trend of my thoughts on the subject.

The complexity of the superficial deposits is evident to all who have studied a typical glaciated area in detail, and the widely

¹ Quart. Journ. Geol. Soc., vol. lxi, 1905, p. 68.

² Geogr. Journ., July, 1907, p. 37.

³ "Glacial Phenomena of the country between the Tyne and the Wansbeck": Trans. Nat. Hist. Soc. Northumberland, etc., 1914. "Glacial Geology of Northumberland": *ibid.*, 1908.

⁴ "Glacial Deposits around Newcastle-upon-Tyne": Proc. Univ. Durham Phil. Soc., 1909.

⁵ "Glacial Phenomena of the Vale of Derwent": *ibid.*, 1909.

⁶ "The Scandinavian Drift of the Durham Coast": Quart. Journ. Geol. Soc., vol. lxxi, 1915, pp. 53-82. "On a Deposit of Interglacial Loess and some transported Freshwater Clays on the Durham Coast": Quart. Journ. Geol. Soc., vol. lxxv, pt. iii, 1920, pp. 173-203.

⁷ "The Preglacial Wash": Proc. Univ. Durham Phil. Soc., 1906. "Borings at Derwenthaugh and Durston": *ibid.*, 1909. "Geology of N.E. Durham and S.E. Northumberland": Geol. Assoc., 1912, etc. There is also a large amount of carefully recorded data in the Boulders Com. Reports of the Univ. Durham Phil. Soc., 1905-12.

diverse views that are still held regarding their origin are an evidence of the difficulty experienced in the interpretation of the phenomena. Accepting as definitely proved that the greater part of the Drift is the product of an ice-sheet, the main controversy now centres round whether there were true Interglacial episodes in the formation of the Glacial deposits; some geologists asserting that the evidence proves there was a succession of Glacial epochs in the Pleistocene Period¹ and some that our era may even be an Interglacial one, while others affirm that there is no evidence of any such intervals in the Glacial deposits of Britain.² As I propose to discuss the evidence that has been advanced recently in favour of Interglacial periods in the Drift of the north-east of England³ it may be well to consider what is meant by such periods, and the nature of the evidence that seems to be necessary to prove that they occurred. The subject is specially complicated because of the difficulty of distinguishing in a limited area an interval of ice-retreat from an Interglacial period, also because there are no exact criteria by means of which Interglacial deposits can be differentiated from interval-deposits or even sometimes from fluvio-glacial beds. If an area has once been glaciated and the ice has retreated, it is obvious it may be reglaciated without a true Interglacial period intervening, for by such an epoch we imply not only the retreat of the ice from a limited area and its subsequent return, but the disappearance or almost total disappearance of the ice from the main gathering grounds (produced by the oncoming of a warmer climate over the whole glaciated region) and then the regrowth of the ice-sheet and the reglaciation of the area considered. Within the limits of the country studied it might be difficult to distinguish a temporary retreat of the ice from an Interglacial period, as they might be marked by the same phenomena, although to a less extent and over a smaller area in the one case than the other. Interglacial periods might be signalized on a marine area by the production of a shore-line and the laying down of deposits, on a land area by the formation of lakes and lake deposits, plant beds, loess deposits, and by a considerable amount of denudation; and somewhat the same phenomena, although on a lesser scale, might mark in a limited area a retreat of the ice from it alone. The only way in which an Interglacial epoch can be proved is by showing that the retreat of the ice took place over the whole glaciated region at the same time. It might obviously be impossible to distinguish in one area the phenomena of an interval of ice-retreat from those of a true Interglacial period; thus the difficulty that has arisen in connexion with the Interglacial problem is due in the first place to the non-recognition of the fact

¹ J. Geikie, *The Great Ice Age*. And other authors.

² Lamplugh, Address to the Geological Section, British Association, York, 1906, etc. It has also been asserted recently by a Swiss geologist that there is no evidence of true Interglacial periods in the Glacial deposits of Switzerland.

³ Trechmann, op. jam cit., Quart. Journ. Geol. Soc., 1920.

that ice-retreat does not necessarily imply an Interglacial period, and in the second place that sweeping generalizations have been made before the phenomena in different areas, due to the intervals of ice-retreat, have been correlated. If, however, this question is to be finally solved it will only be by the working out of deposits, etc., due to the episodes of ice-retreat in each area and their careful correlation, that it will be found if such intervals are so widespread as to be really Interglacial in character.

I would therefore suggest that until this problem has been more fully investigated the term "Interval-in-the-Glaciation" of an area be used when only a limited extent of ground is being studied and not Interglacial period to designate epochs of ice-retreat, and that the term "Interval-deposit" be applied to beds formed during such periods, until by an accumulation of evidence they are proved to be really Interglacial in character. This would tend to define the problem clearly, and to do away with the assumption that any deposits which are not of direct glacial formation in the Drift are Interglacial. The chief difficulty in the acceptance of a series of Interglacial periods is found in the fact that it is difficult to correlate the phenomena that have been taken to mark such episodes in different areas; indeed, it has appeared to some geologists that a change in the foci of ice accumulation and consequent direction of maximum movement might explain most of the phenomena, rather than a succession of Interglacial epochs. If the term "Glaciation-interval" was adopted, and the effects produced in such intervals were gradually worked out as regards their relative importance and extent, and afterwards, if possible, correlated in different districts and later in different countries, it would ultimately be possible to find out whether any intervals were of such extent and importance as to constitute true Interglacial periods. Time alone is not the factor, as an "Interval-in-the-Glaciation" might be as prolonged as an Interglacial period, but it might, however, only be of short duration. No "Interval-deposit" or "Interval-denudation" should be accepted as Interglacial until it is definitely proved to be so. Only in some such way will a really sound general idea of the Glacial deposits be obtained, and it be settled whether they are the result of one continuous glaciation, or of a succession of Glacial epochs.

The subject is further complicated by the difficulty of distinguishing true Glacial from Interglacial deposits, and both of these from beds laid down during an Interval-in-the-Glaciation. Some geologists have regarded the thick sands and gravels occurring in the boulder-clay of the North of England as Interglacial, but some of them may not even be Interval-deposits. They may only be of fluvio-glacial origin, and have been formed during periods of periodic and seasonal ice-melting. There are, however, some beds which may be Interval- or even Interglacial deposits, and their inclusion as such may bear no relation to their

thickness or extent; e.g., the local deposit of sands and gravels at Horsebridge Head, north of the mouth of the Wansbeck,¹ resting on the bed-rock beneath typical boulder-clay, which has been described by one writer as a Preglacial shore-line and by another as the deposit of an early Glacial stream, may have been deposited during an Interval-in-the-Glaciation of Eastern Northumberland or may even be Interglacial; while, on the other hand, the bed of loess at Warren House Gill lately described by Trechmann as an Interglacial deposit² may not be such, but may be an Interval-deposit marking an important episode in the glaciation of East Durham between the deposition of the Scandinavian and British drifts. (No deposits of peat, plant beds, etc., with a temperate flora are yet known in the Glacial deposits of Northumberland and Durham, and so need not be discussed in this paper.)

There is another point to which the greatest attention should be paid if the Interglacial problem has ever to be solved, and that is the exact use of the terms Pre-, Inter-, and Postglacial. A bed beneath boulder-clay is not necessarily Preglacial, as e.g. the deposit at Horsebridge Head or the Sewerby raised beach at Bridlington (both of which have been considered to be Preglacial; the only thing certain is, however, that they were formed prior to the Glacial deposit under which they lie). In the same way a bed occurring in the boulder-clay which was not formed or not directly formed by ice is not necessarily Interglacial, and beds resting on typical boulder-clay with only recent deposits above are not always Postglacial.

The difficulties met with in the working out of the sequence in the Drift of an area are due to several causes, the principal of which are (a) the irregular surface on which it rests, (b) the possibility of the moraine profonde of one ice-stream being overlain by that of another from a different region during one continuous period of glaciation, (c) the possibility of the moraine profonde, etc., of one ice-stream being entirely removed by another ice-flow without an Interglacial period or even a "Glaciation-interval" between, (d) the possibility of some of the deposits being laid down by water without even an "Interval-in-the-Glaciation", and (e) (as a result of these) the complex manner in which the beds change from point to point so that it is exceedingly difficult to correlate them. Every worker in the field on the Drift must have been impressed by the complexity of the deposits, the detailed and exact observation that is necessary to determine the mode of origin of certain beds, or to work out the sequence of events, and by the great need there is for the exact use of terms in describing the formations.

There are certain features of the Glacial and Postglacial phenomena of the two north-eastern counties on which most glaciologists would

¹ A fuller description of this bed is given later.

² *Op. cit.*, 1920, p. 187.

agree. I propose briefly to summarize these, and subsequently to discuss more controversial and indefinite subjects. The most important of the former are:—

(1) In Preglacial times—probably starting with the Miocene—the surface of Northumberland and Durham was eroded by a series of easterly-flowing streams, which were not adjusted to the present coastline.¹ The maximum proved depth of the Preglacial valleys beneath sea-level is 169 feet, occurring at Dunston, west of Gateshead, near the junction of the “Wash”² and the “Tyne”.³ These mature watercourses probably were considerably and unevenly deepened by glaciation. Those which lay in the same direction as that of the ice-movement had a series of rock basins developed in them. In my paper on the superficial deposits I prove that the slope of the bed-rock of the “Tyne” is of a switchback nature,⁴ a feature probably due to the scooping out of the softer beds by the Tyne glacier.⁵ In valleys such as the “Wash”, which lay across the direction of the ice-flow, the slope of the Preglacial Thalweg is, however, continuously in one direction.⁶ The depth of the “Tyne” at its mouth is not so great as it is further inland nor as that of the “Wash”, and I am of the opinion that this is in part due to the uplift that produced the Postglacial raised beaches having been more accentuated in the coastal region. It would appear certain that at some time prior to the Glacial period the country was more elevated and that the constructional shore-line lay far to the east and north of the present one,⁷ but there is no evidence in the two north-eastern counties as to the position of the coastline immediately prior to the oncoming of the Scandinavian ice-sheet.⁸

(2) Before this great outflow, Teglial, Cromerian, and other deposits were laid down on the North Sea area, and some of these were pushed forward by the advancing ice.⁹

(3) The first ice to reach the east of Durham was that from

¹ Geogr. Journ., July, 1907.

² In this paper all Preglacial valleys are denoted by inverted commas.

³ “Note on Borings at Derwenthaugh and Dunston”: Proc. Univ. Durham Phil. Soc., 1909.

⁴ Quart. Journ. Geol. Soc., vol. lxi, 1905, p. 76.

⁵ Merrick, who has studied the Tyne valley very minutely, has also come to the conclusion that rock-basins were developed along it.

⁶ “The Preglacial Wash”: Proc. Univ. Durham Phil. Soc., vol. ii, 1906, p. 5.

⁷ Geogr. Journ., July, 1907, p. 37.

⁸ The buried Chalk cliff and associated deposits at Sewerby, near Flamborough Head, is a little above sea-level. Lamplugh states “that they prove that at the beginning of glacial times the North Sea held possession of its basin, and with a surprisingly slight difference from the present level”. I have always doubted that the level at the beginning of Glacial times was the same as the present. I consider it to have been more elevated. It is not certain that the Sewerby raised beach is not an Interval-deposit. (Or, as suggested by Trechmann, *op. cit.*, p. 190, an Interglacial one.)

⁹ Trechmann, Quart. Journ. Geol. Soc., vol. lxxv, pt. iii, 1920, p. 193.

Norway¹—the Scandinavian Drift being a “pure culture” of Norwegian rocks, together with such material as it obtained in its passage across the North Sea.²

(4) The course of events after the first oncoming of this ice-sheet is difficult to decipher (as the reading of it depends on whether Interglacial periods are accepted or not, and also on the manner in which it is thought certain beds, etc., were produced),³ but of the final period of glaciation we can form a fairly clear picture. During this epoch the coastal area of Northumberland and Durham was invaded by ice from several regions. There were four main ice-streams⁴ from the west, all of which received a southerly trend along this area due to the pressure of the invading sheet from the Continent. These four western flows were (a) one down the Firth of Forth (Forth ice),⁵ (b) one down the Tweed which swept round the Cheviots (Tweed-Cheviot ice), (c) a broad stream from the south-west of Scotland and the Lake District which came over the Northumberland moors, was confluent with a small Alpine glacier down the South Tyne valley, and filled up the Tyne valley (Lake District ice, south-west of Scotland ice, Northumberland ice or Tyne valley ice) and (d) one from the Lake District over Stainmoor, bringing with it the Shap boulders and confluent between Cotherstone and Middleton⁶ with a glacier down the Tees valley (Lake District (Shap) ice,⁷ Stainmoor ice or Tees valley ice). The indicator boulders and the direction of the glacial striations prove that these main flows, following the general contour of the country, moved eastwards in more or less parallel lines until they came under the influence of the Scandinavian ice-sheet,⁸ which diverted them

¹ Professor Bonney (Presidential Address, Brit. Assoc., Sheffield, 1910, p. 23) has endeavoured to show that the Norwegian deep off the south-west coast of Norway would offer a difficulty to the passage of an ice-sheet, but I am in agreement with Dr. Trechmann when he states that this deep need not be considered as presenting a difficulty, and I also consider that the evidence (distribution of boulders, marine shell-bearing gravels and sands pushed inland, etc.) proves that the Scandinavian ice did actually move over the North Sea area, and that a lobe impinged on the Durham coast near Castle Eden.

² Trechmann, *op. cit.*, p. 186.

³ e.g. the deposit at Horsebridge Head.

⁴ Minor glaciers in the Cheviots and Pennines are not considered here, e.g. a glacier came down the Wear valley and was confluent with the Northumberland ice on the north and Lake District (Shap) ice on the south.

⁵ Boulders of olivine-basalt, most probably from the Firth of Forth, occur in the clay at Fulwell Quarries and of St. Abb's porphyrite in that near Tynemouth.

⁶ Three miles and 8 miles west of Barnard Castle respectively.

⁷ It appears highly probable that boulders of Shap granite do occur in the Drift of the Tyne valley. The evidence for their occurrence is very strong.

⁸ Along the coast of Northumberland from Bamborough to the Wansbeck there are two boulder clays of different origin, a lower typical bluish clay mainly of western derivation and an upper reddish clay of Tweed valley and northern origin. Smythe, *Glacial Geology of Northumberland*, p. 94. In a depression at Hartlepool there is a boulder clay with only Western erratics (Trechmann, *op. cit.*, 1920, p. 191), and at Horsebridge Head there is a deposit containing Scottish rocks beneath the Western derived boulder clay.

towards the south, so that they formed a Piedmont glacier. This composite ice-flow moved parallel to the coast of Northumberland and Durham.¹ They also prove that this was the direction of the ice-streams before they began to retreat from North-East England. Along the coastal border of Northumberland and Durham all the observed directions of the striations have this southerly trend. In Northumberland on the open west country they are from west to east, but along a coastal belt about 12 to 14 miles wide there is a distinct series all directed southwards. In one or two places a few miles inland, as at Burradon and South Charlton, there are two sets of striations, an earlier easterly and a later southerly.² In Durham, owing to the more irregular contour of the eastern area, this belt is not so distinctly marked or has not yet been so clearly worked out, but the same orientation is clearly observable along the entire coastal region into North Yorkshire.

STRIATIONS ALONG THE COASTAL BORDER OF NORTH-EAST ENGLAND.*

Farne Islands	S.S.E.
Buddle Bay	S.E. and S.S.E.
Swinhoe†	S.W.
Chathill	S.S.E.
Newton Sea Houses	S. 35° E. and S.
South Charlton (two striations)	{ earlier E. later S.
Little Mill Quarries (two striations).	{ earlier S. 17° E. later S.S.W.
Near mouth of Coquet	S.
Horsebridge Head (mouth of Wansbeck)	S.
Burradon (three striations)	{ earliest 56° N. of E. 20° S. of E. latest 44° S. of E.
Kenton Quarries (near Newcastle)	S.E.
The Flatts, North Shields	S.S.E.
Roker, Sunderland‡	W.S.W.
Fulwell Quarries	S.
Salterfen Rocks (2 miles S. of Sunderland)	S. 17° E.
Haswell Quarry	S.
Wingate	S. 10° E.
Eaglescliffe	W.S.W., S.W., and S.W. by W.
Hob Hill, Saltburn	S.E.

* From records by Smythe, Trechmann, Kendall, Tate, Barrow, and myself.

† From an old unconfirmed record by Tate.

‡ Observed by Professor Kendall. It is more westerly than the rest of the striations round Sunderland, but the rock fragments found in the Grindon Kaim suggest that the ice was moving in this direction at one period in this area, e.g. fragments of Concretionary Magnesian Limestone occur in it west of the outcrop of that rock.

At the end of this period of maximum glaciation in North-East England the combined Forth and Tweed—Cheviot ice was moving due south along the coastal border, the ice from the Lake District

¹ Smythe, *op. cit.*, pp. 89–90.

² We as yet know nothing about either the Indicator boulders or the direction of the striae in the floor of the Preglacial “Sleekburn”, “Tyne”, or “Tees”.

and South-West Scotland streaming across Western Northumberland was pressed south-eastwards over North Durham, and the Tees valley ice was diverted southwards. The northern ice that moved down the coastal region of South-East Northumberland and East Durham thus brought with it to these regions Scotch, Cheviot, Lake District, and Northumberland boulders, and to the Cleveland area all these together with Scandinavian rocks.

(5) During the same epoch this coastal ice carried with it in its passage southwards shore and other deposits. These were pushed inland, and being reassorted by glacial streams were deposited in mounds¹ along the margin of the melting ice-sheet, the Grindon, Warden Law, and Sheraton Kaims of East Durham being formed.

In his work on the glacier-lakes of Northumberland, Dr. Smythe has proved that the western ice from South-West Scotland and the Lake District was the first to retreat in this county,² and the evidence corroborates this in North-East Durham, as the Grindon and Warden Law³ Kaims to the west of Sunderland⁴ were formed on the free margin of the Tweed-Cheviot ice. Near Warden Law, cutting across the Permian escarpment, is a dry channel which may have been formed by the waters from the glacial streams that deposited this Kaim and the associated sands and gravels. The country lying on the western boundary of this ice-sheet was free from ice in this region at that time. In the south of the county the shell-bearing Kaims at Sheraton were similarly formed on the free margin of the same ice-sheet,⁵ and the shell-bearing spreads of cemented sand and gravel in South-East Durham are also fluvio-glacial deposits formed under similar conditions.⁶

(6) During the period of the maximum pressure of the combined ice-flows along the coastal region of North-East England the glacier-lakes of Cleveland were formed, the phenomena associated with which have been so fully described by Professor Kendall.⁷ These lakes lasted until the beginning of the retreat of the ice from the coastal region.

(7) About the same time a system of ice-dammed lakes existed in

¹ Adopting the classification of fluvio-glacial mounds and ridges into Kaims, Eskers, and Ösars proposed by Professor Gregory in a paper read before the Royal Society on April 29, 1920 (*GEOL. MAG.*, June, 1920), those of Northumberland and Durham are all Kaims. They were formed along the margin of the ice-sheet, some being deposited in glacier-lakes and others not.

² "Glacial Geology of Northumberland": *op. jam cit.*, p. 104.

³ Warden Law is 5 miles inland and 646 feet above sea-level. The gravels are 200 feet thick. Grindon is about the same distance inland.

⁴ "Geology of N.E. Durham and S.E. Northumberland": *op. jam cit.*, p. 102.

⁵ A list of shell-fragments collected in these Kaims by Trechmann is given in the *Quart. Journ. Geol. Soc.*, vol. lxxv, pt. iii, 1920, p. 194. They are 4 miles inland, and about 400 feet high.

⁶ I have collected shell-fragments from the gravels at Dalton Piercy, near Hartlepool.

⁷ *Quart. Journ. Geol. Soc.*, vol. lviii, 1902, pp. 471-571.

the Cheviots,¹ and in the tributary valleys of the Tyne and Tees.² The overflow channels connected with the latter are one of the most marked physiographical features of South-West Northumberland and Western Durham. The glacier-lake of the Derwent valley³ was formed when the Lake District-Northumberland ice was feeling the pressure of the coastal ice many miles inland.

(8) The phenomena connected with the period of ice-retreat are specially well-marked in Northumberland, and have been very carefully worked out by Smythe.⁴ He has proved that the first ice to retreat in that country was the western flow from South-West Scotland and the Lake District, while the Tweed-Cheviot ice still occupied the coastal border.⁵ A system of temporary lakes was formed; the numerous overflow channels from these and the Kaims deposited by streams flowing into them from the free margin of the ice-sheets are among the most distinctive features of the physical geography of Mid-Northumberland. About the same time the gap at Ferryhill was cut by a stream flowing from waters held up by ice in the Tees valley,⁶ and the gorge of the Wear near its mouth was probably started by an overflow stream when the Tweed-Cheviot ice was holding up temporary waters to the west and finally retreating from North-East Durham. Further to the west the phenomena connected with the retreat of the ice are also in places clearly observable. Beyond the limits of Western Northumberland the retreating ice held up waters of some magnitude, the overflow channel from which is the great swire of the Tyne Gap.⁷ The retreat of the Lake District (Shap) ice across Stainmoor is distinctly marked on Cotherstone Moor by the well-developed group of Kaims known as the Burners Hills. The contrast between these conical fluvio-glacial mounds and the flat-topped table-like Millstone Grit hills—butte- or mesa-like remnants of a small dissected plateau—of Goldsborough and Shacklesborough on either side of them forms one of the distinct features of the country lying between Barnard Castle, Bowes, and Middleton-in-Teesdale.

(9) While the position of many valleys now dry or still drainage channels was determined by the overflow channels from glacier-

¹ Kendall & Muff, *Trans. Edin. Geol. Soc.*, vol. viii, 1902, pp. 226-30; Woolacott, *Geogr. Journ.*, July, 1907; Smythe, *Glacial Geology of Northumberland*, 1912.

² Dwerryhouse, "Glaciation of Teesdale," etc.: *Quart. Journ. Geol. Soc.*, vol. lviii, 1902, pp. 572-608.

³ Herdman, "Glacial Phenomena of the Vale of Derwent": *Proc. Univ. Durham Phil. Soc.*, vol. iii, pt. iii, 1909.

⁴ *Glacial Geology of Northumberland*, 1912.

⁵ *Ibid.*, p. 104.

⁶ Woolacott, *Geogr. Journ.*, 1907, p. 43, and Trechmann, *op. cit.*, *Quart. Journ. Geol. Soc.*, 1920, p. 192.

⁷ Smythe, *Glacial Geology of Northumberland*, p. 106. The course of this valley was probably first of all determined in Preglacial times by the Irthing, which appears to have been then a tributary of the South Tyne. Woolacott, *Geogr. Journ.*, July, 1909, p. 8.

lakes or by streams flowing from the margins of the ice-sheets, yet when the ice had finally left the country it was the relative contour of the surface of the bed-rock and drift that was the determining factor in valley development. The valleys of the Tyne and Tees and Upper Wear were superimposed on the partly filled Preglacial channels, but many of the smaller of these had been entirely obliterated, and the direction of the Postglacial streams bear no relation to them. When the direction of ice-flow had been across the pre-existing valley, there was left after the ice had vanished a thicker deposit of Drift on the lee-side of the valley than on the other. This contour of the glacial deposits forced the new streams to erode their courses on the comparatively driftless side of the valley. The most-marked channel thus produced is that of the Wear from Durham past Finchale Abbey towards Chester-le-Street,¹ which is here developed in rock and boulder-clay on the eastern side of the "Wash". The Wear valley thus is a composite one, being a combination of three types—in its higher reaches it is superimposed on the pre-existing channel, from near Durham to Chester-le-Street its course was determined by the Drift-contour, but the gorge near its mouth was originally eroded by an overflow stream from ice-dammed waters, and was finally developed since the uplift of the Durham coast in late Glacial or Postglacial times.

(10) The dry valleys of Northumberland and Durham which form such a distinct feature in its physiography have been produced in three distinct ways, viz.: (a) some are Preglacial channels which have not been filled up by drift, (b) some are the forsaken overflows from glacier-lakes, (c) some were formed by streams that flowed from the margin of the ice-sheet—on to country which was not occupied by lakes—and are thus associated with Kaims.

(a) The dry valleys of the Permian area round Sunderland, of which Tunstall Hope is a typical example, are mature, comparatively driftless valleys, whose outlets were blocked by material deposited by the Tweed-Cheviot ice as it moved along the coastal region and by the marginal deposits of the sea as the raised beaches were being formed. (b) The valleys which were eroded by the overflow waters from temporary lakes held up by ice are singular in form and position and bear no relation to the present drainage or to any possible river drainage of the past.² They are usually trench-

¹ There are several of this type in Northumberland. Smythe, op. cit., p. 112.

² Professor Bonney, discussing the glacier-lakes of Cleveland (Pres. Address, B. A. Sheffield, 1910, p. 29) has suggested that "the so-called overflow channels much more closely resemble the remnants of ancient valley-systems . . . and they suggest that the main features of this picturesque upland were developed before rather than after the beginning of the Glacial Epoch", but a detailed examination of most of the more important dry channels of Northumberland, Durham, and Cleveland has convinced me that—with certain exceptions, as for example some on the Permian area of East Durham—it is impossible for the great majority of them to be the remnants of old drainage systems.

like in character with flat bottoms and have obviously been cut quickly under peculiar conditions. They breach watersheds, sever spurs, and trench hill-sides. Some of them cut through the drift into the bedrock, thus affording evidence of their origin in late Glacial times. Dr. Smythe has mapped about seventy in Northumberland, and in Durham there are many well-developed gorge-like examples. Owing to the Nunatakkr of the Crossfell ridge preventing the western ice from sweeping over South-West Northumberland and the west of Durham, this country was not glaciated to the same extent nor in the same way as the main part of Northumberland. (The Cheviot massif had its own local glaciers and its borders were swept by the Tweed ice on the north and the western ice on the south, and is therefore also a distinct area.) The glaciers in this protected region of West Durham and South-West Northumberland were valley-glaciers, Alpine in type, and on its northern and southern borders the glacier-lakes in the tributary valleys of the Tyne and Tees were formed on high ground, and the swires thus cut across high watersheds and are sometimes most striking in their appearance and position. In Mid-Northumberland the phenomena due to the retreat of the ice can, be very clearly studied. Dr. Smythe has shown that the line of junction between the Tweed-Cheviot coastal ice and the Western ice was a position of cleavage and weakness, and that temporary waters were held up on the ice-free country between these sheets as the ice-streams decreased, the overflow valleys and the fluvio-glacial Kaims being exceptionally well developed.

(b) The glacier-lake phenomena connected with the Tees ice is specially interesting near Middleton. The tributary valleys of the Egglesthope Beck and the Blackton Burn had lakes formed in them, and here both direct overflow channels across the watershed between the Tees and Wear and a severed spur between the two minor valleys are clearly marked. Cutting across the ridge of Knotts Allotment beneath the Millstone Rigg, between the Egglesthope and Blackton Burns, are a well-defined series of flat-bottomed nicks, one below the other—notches in the spur developed by overflow marginal streams as the Tees glacier diminished in volume. This remarkable severed spur forms one of the most distinct features of the landscape between Barnard Castle and Middleton. It is perhaps worthy of note that some of these slacks afford a means of roughly determining the thickness of the ice in the main valley when they were formed; thus the trenches on this spur lie between the 1400 and 1500 contour, while the height of the base of the Tees valley at this point is from 600 to 700 feet. As the highest notch was cut at the time of the maximum thickness of the Tees valley ice, the glacier occupying this valley between Middleton and Romaldkirk must have been 700 or 800 feet thick.¹

¹ The Tees valley glacier was probably held up for a time in this region by the Lake District (Shap)-ice sweeping over Stainmoor.

(c) Some swires, and also valleys which are now permanent water-courses (to which, however, the streams in them are often obviously not adjusted) were directly formed by streams flowing from the ice-margin, whose load of sediment was deposited as a Kaim. The Burners Hills, already noticed as occurring on the Cotherstone Moor, have drainage channels connected with them, and the trench now occupied by the How Beck is the course of the escaping glacial waters. Dr. Smythe has also noticed the association of Kaims with dry valleys in Northumberland.¹ The glacier-streams in such cases did not flow directly into lakes, and hence sometimes developed wide and deep trench-like slacks.

(11) One of the most striking features of the superficial deposits of these two counties is the great amount of erosion and reassortment of glacial material that has taken place along the main valleys of the Tyne, a feature which was first clearly pointed out by Lebour.² The river terraces formed from the Drift in this valley between Bardon Mill and Haydon Bridge by the Glacial and Postglacial streams can be traced as high as the 300 feet contour-line. This is in distinct contrast with the apparently small denudation of the kaims, drumlins, and other surface features of the Drift out of the line of the main valleys, but this may be deceptive as these mounds and ridges may be much reduced in size, although their original contour is still preserved.

(To be continued.)

The World's Copper Production.

By F. H. HATCH, Ph.D., M.Inst.C.E., Past-President of the Institution of Mining and Metallurgy.

THE following article originally appeared in the *Times* Trade Supplement of August 28 last. It is here reprinted with some small additions by the courtesy of the proprietors of that Journal.

The world's consumption of copper at the beginning of the nineteenth century was some 15,000 tons³ per annum. By the end of the century it had increased to over 600,000 tons per annum, and it reached a million tons by the year 1912. In 1917 it was close on one and a half million tons.

This era was one of continually growing engineering activity, and the high consumption of copper in the latter part of the period was chiefly due to the great demand for that metal for purposes of electric power generation and transmission, while during the late

¹ *Glacial Geology of Northumberland*, p. 102.

² *Geology of Northumberland and Durham*, p. 15, and "Certain Surface Features of the Glacial Deposits of the Tyne Valley": *Nat. Hist. Trans. Northumberland*, etc., vol. xi, pt. iii, 1893.

³ Metric tons throughout.

War a considerable use was made of the metal and its alloys in the manufacture of war material.

Such remarkable increases in consumption demanded fresh sources of supply, which did not fail to be discovered. During the nineteenth century new deposits of copper ore were developed, at first in South America and in Cuba, and, later on in the century, in the United States, Australia, South Africa, and Canada. Another source of supply from the sixties onward was the copper smelted at British ports from the cupriferous pyrites imported in vast quantities from Spain and Portugal for its sulphur content.

In the following table will be found the world's production of copper for every fifth year from 1803 to 1918.¹

TABLE I.
WORLD'S PRODUCTION OF COPPER FOR EVERY FIFTH YEAR.

Year.	Metric Tons.	Year.	Metric Tons.
1803	15,000	1863	96,000
1808	16,000	1868	110,000
1813	17,000	1873	122,000
1818	19,000	1878	154,000
1823	23,000	1883	199,000
1828	27,000	1888	262,285
1833	31,000	1893	310,704
1838	36,000	1898	441,868
1843	42,000	1903	609,985
1848	52,000	1908	790,238
1853	63,000	1913	1,002,300
1858	78,000	1918	1,395,160

At the beginning of the nineteenth century the world's copper consumption of some 15,000 tons per annum was easily covered by the production of the United Kingdom, Russia, (Bogoslovsk), Japan, Chile, Sweden (Falun), Norway (Röros), and Germany (Mansfeld), together with small amounts from other countries. This order is that of the importance of the contribution. The chief producer—the United Kingdom—furnished nearly a half of the whole world's production from mines in Cornwall, Devonshire, Anglesey, and Ireland.

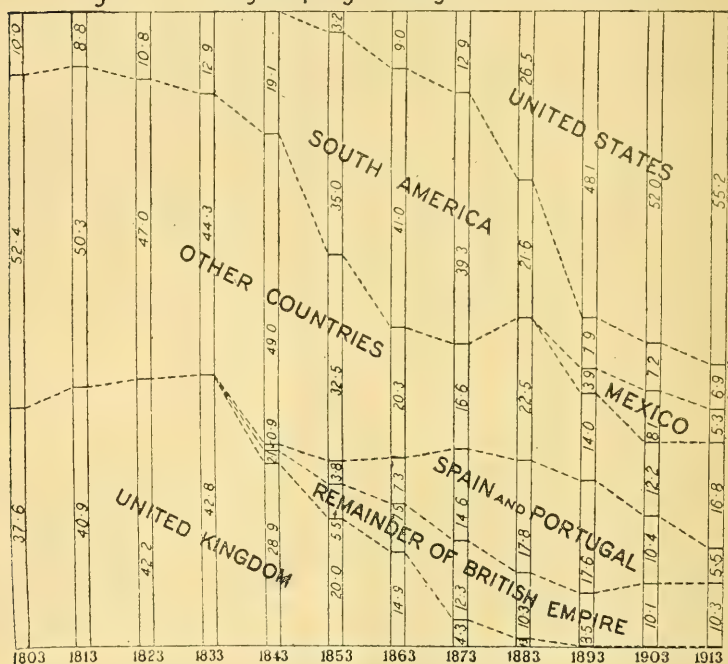
The introduction of copper sheathing for wooden ships was responsible for a gradual but not rapid increase in consumption until the forties, when it reached close on 40,000 tons per annum. The United Kingdom was still the largest producer (accounting for a third of the whole), followed by Chile, Russia, and Japan.

¹ The figures for 1803 to 1883 have been estimated from the world's decennial production given in Messrs. Nicol Brown & Turnbull's *A Century of Copper*. Subsequent figures up to the year 1908 are from the Chief Inspector of Mines' Report, part iv. The figure for the year 1913 is from Merton's Tables, and that for 1918 from the *Engineering and Mining Journal*.

The expansion of the engineering trades then caused a more rapid increase of consumption, and by the middle of the century it reached close on 60,000 tons per annum. British Colonies (Australia and the Cape) and the United States now began to take part in production, but the United Kingdom maintained its lead, furnishing a quarter of the whole. The countries next in importance were Chile, Cuba, Russia, and Japan. The Chilean output was from rich oxide ores, which were imported into the United Kingdom for smelting in Swansea. Large quantities of similar ores were brought

COPPER FROM HOME ORES.

Diagram of Percentage Output by Producing Countries from 1803-1913.



from Cuba; but imports from this source ceased about 1870. The British Colonies contributed 5 per cent of the total, mainly from the Kapunda and the Burra-Burra mines, discovered in South Australia in the forties; while the United States' contribution of two per cent was derived almost entirely from the Lake Superior native copper mines, which began to produce in 1845.

For the next twenty years the consumption maintained a fairly uniform rate of acceleration, being about 85,000 tons in 1860 and 115,000 tons in 1870. The increase was met by an expansion of production in Chile, which now exported a considerable proportion of its copper in the form of metal (Chile bars) and regulus; whereas,

previously, high-grade ores had been sent to the United Kingdom for smelting at Swansea. The change was due to the high toll charged by the Swansea works, which drove the Chileans to establish their own local smelters. In 1870 Chile furnished half the total world's production, and thus became the leading producer. The United Kingdom occupied the second place, being followed in order by Spain and Portugal, the United States, Australia, Japan, and Cuba. In 1863 the United States produced 9 per cent and in 1868 10 per cent of the whole. The production of the United Kingdom was 15 per cent of the whole in 1863, decreasing to 9 per cent in 1868. On the other hand, that of the British Colonies rose from 7 per cent in 1863 to 10 per cent in 1868. This was in large measure due to the working of the rich oxide-ores of the Wallaroo and Moonta mines of South Australia, discovered in 1845; but the Great Cobar and other mines in New South Wales contributed, and Newfoundland began to ship ore from Tilt Cove in 1864.

In consequence of the increased demands of the engineering trades, especially in shipbuilding and marine engineering, followed later by the very extensive use of copper in electric power generation and transmission, the world's consumption of copper now began to rise more rapidly; by 1873 it was 122,000 tons per annum, in 1883 close on 200,000 tons, and in 1893, 310,000 tons. This rapid growth in consumption was met by large increases in the production of the United States and of Spain and Portugal: in Spain the Rio Tinto (taken over by an English company in 1876) enlarged its scale of operations and other pyrites mines in the Huelva district of Spain and the neighbouring territory of Portugal became great copper producers. In 1873 the order of contribution was as follows: South America (chiefly Chile), British Empire (17 per cent of the whole, Spain and Portugal (Rio Tinto and Tharsis), United States (13 per cent of the whole), Germany, Japan, and Russia. By 1883 the United States had passed the British Empire (the respective proportions being 26 per cent and 12 per cent), and from that period the production of the United States went up by leaps and bounds. This was brought about, not only by improving the methods of mechanical concentration and smelting, but also by very largely increasing the scale of operations, notably in the rich sulphide mines of Montana, in the native copper mines of Michigan (Lake Superior), and in the large porphyry contact deposits of Arizona.

During this period the output of the United Kingdom (one per cent in 1883) dwindled to insignificance, owing chiefly to the gradual deepening of the Cornish mines and the downward change from copper to tin which characterizes the lodes.¹ The contribution of the British Empire as a whole, however, showed a substantial increase in consequence of the important mining developments which then took place in Australasia, Canada, and South Africa.

¹ The present copper production of the United Kingdom is derived mainly from "precipitate" got by treating water from the old Parys and Mona mines in Anglesey.

The increase in the output of Australasia was due to the development of the Mount Lyell mine in Tasmania; that of Canada to the working of nickel-copper mines at Sudbury in Ontario, gold-copper mines at Rossland in British Columbia, and silver-copper mines at Nelson in the same province. In South Africa copper mines were worked by the Cape Copper Company and the Namaqualand Copper Company in Little Namaqualand, the ore being sent to Swansea partly in the form of matte, partly as a high-grade concentrate.

Table II gives the production of the world, the United States and the British Empire for every fifth year, from 1888 onward.

TABLE II.

Year.	World's Total.	United States.		British Empire.		U.K. alone.	Other countries.
	Tons.	Tons.	% of World's.	Tons.	% of World's.	Tons.	% of World's.
1888	262,000	103,000	39.1	24,000	9.3	1,456	51.6
1893	310,000	149,000	48.1	26,000	8.5	425	43.4
1898	442,000	239,000	54.0	34,000	7.7	640	38.3
1903	610,000	317,000	52.0	62,000	10.1	533	37.9
1908	790,000	427,000	54.1	79,000	10.0	579	35.9
1913	1,002,000 ¹	555,000	55.2	91,000 ²	9.1	421	35.9
1918	1,395,000 ²	848,000 ²	60.8	—	—	182 ³	—

The order of production and the proportion produced by each contributor at the beginning of the twentieth century (1901) were as follows: United States (51½ %), British Empire (11½ %), Spain and Portugal (10 %), South America (8 %), Mexico (6 %), Japan (5 %), Germany (4½ %), Russia (1½ %), Norway (½ %), and Italy (½ %).

The total production of the world for the nineteenth century has been estimated ⁴ at 10,240,000 tons, the chief contributors being: the United States (29 %), South America (20 %), Spain and Portugal (13 %), the United Kingdom (8½ %), Japan (6 %), Germany (4½ %), Australia (4½ %), Russia (4 %), Norway and Sweden (2 %), Mexico (1½ %), Cuba (1½ %), South Africa (1½ %), Canada (½ %). The British Empire as a whole produced 16 %. (See Table III.)

The first decade of the twentieth century saw a production of 7,333,000 tons. During this decade the following countries practically doubled their production: United States, South America (where the biggest increase was in Peru), Mexico, Japan, and Norway. This great advance in production was largely brought about by improvements in the methods of mechanical concentration, which made it profitable to lower the grade of the material mined, and

¹ Merton.² *Mineral Industry.*³ Home Office.⁴ By Nicol Brown & Turnbull in *A Century of Copper.*

thus to attack vast bodies of disseminated ore hitherto untouched, especially in the American States of Arizona, Utah, and Nevada. Other new producers were Serbia and German South-West Africa; Cuba also started work on its sulphide ores.

TABLE III.

THE PRODUCTION OF COPPER IN THE NINETEENTH CENTURY, ARRANGED ACCORDING TO COUNTRIES (STATISTICS DERIVED FROM NICOL BROWN AND TURNBULL'S "A CENTURY OF COPPER").

	Tons.	Tons.	Per cent.
UNITED STATES . . .		2,993,540	29.3
SOUTH AMERICA.			
Chile	1,886,405		18.3
Bolivia	54,210		.5
Peru	34,135		.3
Venezuela	113,850		1.1
Total		2,086,600	20.2
BRITISH EMPIRE.			
United Kingdom . .	864,660		8.5
Australasia	470,219		4.6
South Africa	175,580		1.7
Canada	69,870		0.7
Newfoundland . . .	46,527		0.5
Total		1,626,856	16.0
SPAIN AND PORTUGAL.		1,328,965	12.9
JAPAN		604,200	5.9
GERMANY		472,520	4.6
RUSSIA		420,920	4.1
SCANDINAVIA.			
Norway	103,500		1.0
Sweden	106,680		1.1
Total		210,180	2.1
MEXICO		142,360	1.4
CUBA		139,880	1.4
OTHER COUNTRIES . .		211,468	2.1
Total		10,239,489	100.0

The production of the present decade will exceed ten million tons, that is, it will be more than the whole production of the last century. The widespread use of the flotation method of concentration and the introduction of new processes for leaching the ores direct, brought fresh sources of supply into being at a time when production was being greatly stimulated by urgent war demands. With the coming of peace, however, a temporary fall in consumption was inevitable, and this began to show its effect on production in the year 1919, and will be accentuated in the present year (1920).

It is doubtful, however, whether consumption has reached its highest point. The ever-spreading use of electricity for power, light, and heat means a *per capita* increase of consumption throughout the world, especially in countries such as Russia and China, where hitherto electricity has not come into general use.

TABLE IV.
WORLD'S PRODUCTION OF COPPER, ACCORDING TO COUNTRIES, FOR FIRST DECADE OF TWENTIETH CENTURY, DERIVED FROM HOME OFFICE RETURNS.

Country.	1901.	1902.	1903.	1904.	1905.	1906.	1907.	1908.	1909.	1910.	Total 1901-1910.
UNITED STATES .	273,173	299,151	316,631	368,564	409,103	416,314	394,174	427,547	495,760	489,957	3,890,374
BRITISH EMPIRE .	(63,874)	(52,208)	(61,865)	(64,395)	(70,947)	(73,421)	(75,267)	(78,705)	(72,704)	(78,914)	692,300
Australia .	29,500	25,128	31,410	29,765	35,280	38,771	41,103	38,220	37,680	41,000	
Canada .	18,575	17,767	19,632	19,491	21,590	23,868	25,640	23,811	23,811	25,262	
Cape Colony .	12,443	6,120	7,523	10,654	10,397	5,121	5,631	87,746	8,606	10,415†	
Newfoundland .	2,799	2,703	2,753	3,984	2,859	2,688	1,700	1,567	1,155	1,480	
Sundry .	557	490	547	501	821	973	1,193	1,277	1,452	757	
SPAIN AND PORTUGAL .	(60,625)	(58,894)	(63,058)	(67,541)	(57,637)	(69,950)	(73,061)	(69,160)	(77,087)	(75,387)	672,400
Spain .	54,625	52,417	56,150	60,565	53,120	62,290	64,731	65,625	71,747	71,747	
Portugal .	6,000	6,477	6,908	6,976	4,517	7,660	8,330	3,535	5,340	3,640	
SOUTH AMERICA .	(39,070)	(37,900)	(42,723)	(41,427)	(45,895)	(46,328)	(52,377)	(64,816)	(65,176)	(72,677)	508,389
Chile* .	30,570	26,600	29,086	29,923	29,605	29,626	28,863	42,096	42,726	42,726	
Bolivia .	—	3,600	4,141	2,000	4,045	3,288	2,813	2,039	2,470	2,478	
Peru .	8,500	7,700	9,496	9,504	12,213	13,474	20,681	20,681	19,854	27,347	
Venezuela .	—	—	—	—	32	—	20	—	126	126	
MEXICO .	37,000	43,312	48,976	77,820	69,560	61,600	80,330	43,940	59,780	80,000	602,258
GERMANY .	31,376	30,578	21,782	22,502	24,480	22,000	22,858	22,790	24,719	29,000	252,085
JAPAN .	25,304	27,440	33,245	35,560	33,715	38,515	40,183	41,399	45,793	50,705	371,859
RUSSIA .	8,258	8,258	8,817	10,700	8,840	10,424	14,632	16,850	18,421	22,700	127,900
ITALY .	4,855	4,685	4,344	5,503	4,731	5,232	7,114	3,614	3,174	4,526	47,778
NORWAY .	4,684	4,996	4,180	5,701	7,200	7,613	8,585	7,134	9,900	9,570	69,563
GERMAN S.W. AFRICA .	—	—	—	—	—	26	3,804	6,058	6,671	6,482	23,041
SERBIA .	—	—	—	—	—	763	1,764	2,198	4,209	5,335	14,269
CUBA .	—	—	—	2,045	1,825	1,017	1,912	—	4,146	1,896	12,841
REMAINING COUNTRIES .	5,490	4,430	4,364	3,630	4,329	3,159	5,894	6,027	5,171	5,314	47,798
TOTAL .	553,709	571,852	609,985	705,378	738,202	756,362	781,955	790,238	892,711	932,463	7,332,855

* Including Bolivia.

† South Africa.

The vital question is whether production will be able to meet such heavy demands as are here foreshadowed in view of the approaching exhaustion of some of the existing sources of supply. While the number of companies contributing to the world's production is well over three hundred, about half the total is derived from a score of mines only. Many of these big producers are in America. The United States contributes from its mines in Arizona, Montana, Michigan, Alaska, Nevada, New Mexico, and California over 60 per cent of the world's production; and there are big producers in Canada (Sudbury), Mexico (Cananea, Nacozari, Boleo), Chile (Chuquicamata), Peru (Cerro de Pasco), and Venezuela (Aroa). Japan also has some great mines (Ashio, Besshi, Hitachi, and Kosaka), and the Rio Tinto in Spain, the Mansfeld in Germany, and the Bogoslovsk, Dzansoul, Kyshtim, Sissert, and Spassky mines in Russia should be noted in this connexion. Although existing reserves may be large enough for the immediate future, it is quite certain that some of these large mines cannot have a very long life, and their shutting down would appreciably affect production unless fresh discoveries enable their places to be filled.

The copper recovered from the ore mined throughout the world probably does not exceed 45 lb. to the long ton or two per cent. Exact figures are forthcoming for the United States: in 1906 the average yield for all ores treated was 2.5 per cent; in 1903 it had fallen to 1.67 per cent, and by 1914 to 1.6 per cent; in 1916 it was 1.7 per cent.¹ There is, consequently, not the margin for increasing the available reserves by lowering the grade of the ore mined, such as obtains in iron-ore mining; and any increase in the supply of copper, or, indeed, the maintenance of the present rate of production, must depend in the long run either on the discovery of new deposits, or on the improvement of the treatment methods. During the last decade the world has been searched for new occurrences of copper-ore, and it is certain that the efforts of capitalists and mining engineers will not be relaxed in that direction. Metallurgists also will perfect the existing methods of extraction or find new ones whereby the yield will be increased. B. S. Butler states² that from 5 to 30 per cent of the copper content of the ore at present treated is lost, and if this be so there is room for improvement in this direction.

The United States, by its refineries on the Atlantic seaboard, controls a large proportion of the South American and Canadian output of the metal. Acting in conjunction with the large home production, the effect of this control has been to place the copper market of the world (which for the greater part of the nineteenth century was centred in Great Britain) practically in the hands of the United States. It may be that in view of an increasing consumption the copper magnates who control this market will use their power to limit supplies and drive up the price of copper. These

¹ *The Mineral Resources of the United States*, 1916, p. 642.

² *The Strategy of Minerals*, New York, 1919, p. 153.

considerations lead some to foretell a coming world shortage which will be little less than a famine.¹

On the other hand, great reserves of unworked copper-ore undoubtedly exist in different parts of the world, and in course of time an increased production may be looked for from the resources of Mexico, Chile, and Peru in Central and Southern America, from the Altai, the Kirghiz Steppes, and the Urals in Russia, from the Belgian Congo in Central Africa, and from South-West Africa.

Whether future supplies will equal the demands there are not sufficient data at hand to determine.

The Representation of Stratigraphical Divisions by Shading.

By Dr. J. W. EVANS, F.R.S.

BLACK and white shading is frequently employed in geological maps and sketches, but there is a remarkable absence of uniformity in the means by which different strata have been represented.

There are three purposes for which shading may be employed in geological maps, but these cannot as a rule be satisfactorily effected on the same map. It may be desired to express (1) the lithological characters of the rocks, (2) their stratigraphical position, and (3) their structural relations. For the first purpose it is convenient to use the same conventional shading as is employed in diagrams of sections. It is mainly with the second that I shall deal in the present article. For the third purpose little has yet been done, and I hope to consider the subject on another occasion.

I devised the system of denoting the different divisions of the geological succession, which I shall now describe, for the small scale geological maps published in the portion of the *Handbuch der regionalen Geologie* dealing with the British Isles. One of these is reproduced on a reduced scale in this issue of the GEOLOGICAL MAGAZINE. The geological boundaries were drawn by Dr. Morley Davies and the shading by Miss Reeks, Technical Artist to the Imperial College of Science and Technology.

In this system the pre-Cambrian rocks are distinguished by a north-east and south-west direction of shading (the Charnian strike), the older Palæozoic—Cambrian, Ordovician, and Silurian—by a north-east and south-west direction, the later Palæozoic—Devonian, Carboniferous, and Permian—by a north and south direction, that of the Pennine range, and the Mesozoic by an east and west direction (Hercynian).

The Kainozoic is indicated by crosses and the Quaternary or Anthropozoic by small circles or "birds" (v). In the subdivisions of the strata expressed by each direction of shading, the older rocks are distinguished by continuous lines and the later by

¹ Sidney Brooks in the *North American Review*.

interrupted lines and the intercalation of dots. Further subdivisions can be distinguished by the spacing of the shading, variations in the number of dots, and other devices. In the Kainozoic, the Eocene and Oligocene are shown by diagonal crosses and the Miocene and Pliocene by upright crosses. The Eocene and Oligocene can be distinguished by the opposite or alternating arrangement respectively of the crosses and a similar distinction can be made between the Miocene and Pliocene. Here, again, numerous means can be devised by variations in the forms and relations of the crosses to express minor divisions.

Passage beds, or those in which the outcrops of different strata are too much involved to be separately mapped, may be indicated by a combination of two shadings. The usual symbolic shading for lithological characters can also be combined with this method of shading.

The occurrence of volcanic rocks is indicated by a thickening of the shading. Intrusive rocks are shown in black, or if it is desired to express their age this may be effected by the same shading as that employed for sedimentary rocks but reversed, that is to say in white on black.

REVIEWS.

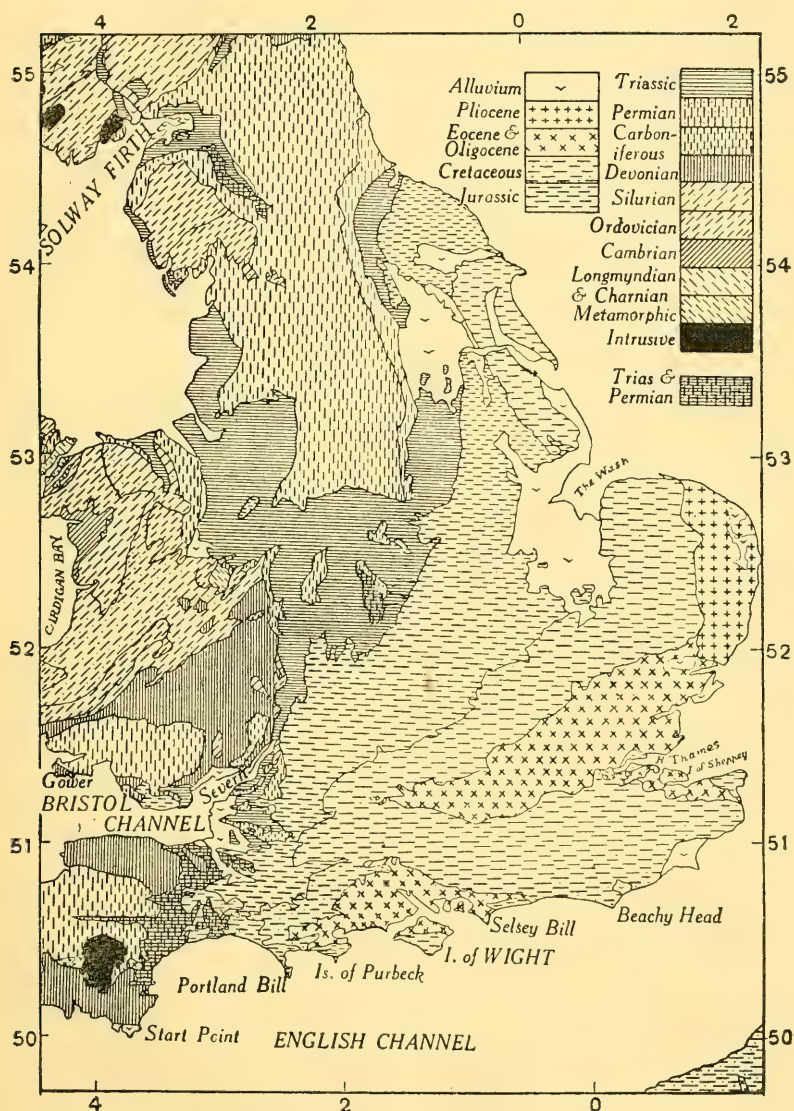
THE BRITISH ISLES. By P. G. H. BOSWELL, G. A. J. COLE, A. M. DAVIES, C. DAVISON, J. W. EVANS, J. W. GREGORY, A. HARKER, O. T. JONES, P. F. KENDALL, L. RICHARDSON, W. W. WATTS, H. J. O. WHITE. Local Editor: J. W. EVANS. With an Appendix: THE CHANNEL ISLANDS. By F. PARKINSON. *Handbuch der regionalen Geologie*, vol. iii, pt. i, 354 pp., with 73 figures. Heidelberg: Carl Winters Universitätsbuchhandlung. 1917.

THIS valuable work forms the first section of the third volume of the *Handbuch der regionalen Geologie*. The manuscript appears to have been completed by 1914, but the War delayed its publication, and the date of issue is given on the cover as 1917. Even now it is difficult to procure the volume in England.

The first twenty-four pages are devoted to the Morphology of the British Isles, England and Wales being dealt with by Dr. A. M. Davies, Scotland by Professor Gregory, and Ireland by Professor Cole. Then follows a short note on British Earthquakes by Dr. C. Davison, and the remainder of the work, more than 300 pages, is devoted to stratigraphy. All the sections relating to Ireland are written by Professor Cole, and in most of the geological systems the igneous rocks are discussed by Mr. Harker. In the case of the Ordovician and Silurian systems, however, the volcanic rocks are described along with the sedimentary deposits, while the intrusive rocks are dealt with separately by Mr. Harker. With regard to the other sections, Professor Gregory describes the pre-Cambrian of Scotland, Professor Watts the pre-Cambrian of England and Wales and the Cambrian and Ordovician of Great Britain; Professor O. T. Jones takes the Silurian, and Dr. Evans the Devonian, while Professor Kendall is responsible for the Carboniferous, Permian, and Quaternary. The Trias and Rhætic, in accordance with German custom, form two distinct sections, which are written by Mr. Linsdall Richardson and Professor Boswell. The Jurassic and Lower Cretaceous are dealt with by Dr. A. M. Davies and Professor Boswell, and the Upper Cretaceous and Tertiary by Mr. Osborne White. Finally there is an appendix on the Channel Islands by Mr. Parkinson. In the GEOLOGICAL MAGAZINE it is not necessary to add that these names are a sufficient guarantee of accuracy.

The space allotted to morphology is too small to allow of an adequate treatment of so complex a subject; but the stratigraphical section is a very complete account of British stratigraphical science as it was a year or two before the War. It is approximately on the same scale as Jukes-Browne's *Stratigraphical Geology*, but local detail is not so strongly emphasized as in that work. It is not that the local detail is omitted, but that it is more subordinated

to the general description and is not accentuated by heavy type. For this reason the book is in general easier and more interesting to read, but it is not quite so handy for occasional reference. The very full correlation tables, however, will be found helpful in this respect.



Part of a Geological Map of the British Isles, reproduced on a reduced scale from the *Handbuch der regionalen Geologie*.

The number of pages given to the pre-Cambrian and Palæozoic rocks is 171, while the Mesozoic and later formations occupy 132. A work of this kind is not a complete presentation of facts, but a presentation of facts so far as they are known; and judged on this basis the space devoted to the older rocks is disproportionately large. But perhaps this is unavoidable. A system which occurs in widely scattered outcrops may require more room for its description than a system which forms a continuous belt, although—and, indeed, it may be *because*—our knowledge of the former is much less complete.

It would evidently be impossible, without unduly extending this notice, to criticize the entire book in detail; and it would be invidious to select the work of any single author. It must accordingly suffice to say that the whole scheme is admirably carried out, and that errors are few and, within the limits of our present knowledge, unimportant. Exception, however, may be taken to a statement on the first page. According to Dr. Morley Davies, the terms Caledonian and Armorican, as applied to folds, merely denote direction. In making this statement he follows Professor Lapworth, who at a meeting of the Geological Society in 1902 gave a similar definition. But this is not the meaning of the terms as originally proposed, nor is it the sense in which they are now used by most geologists, or, indeed, by any geologist outside the British Isles. The English language is not so poor that it requires the invention of special terms to indicate direction, and direction only; though some convention is desirable to avoid such clumsy expressions as "N.E.—S.W. folds". If, however, the geologist cannot prevail upon himself to use so simple a word as north-east, he should at least select an adjective which is not already employed in the same connexion, with a different significance.

The book is not intended for the novice, but the advanced student will find it very useful. For the trained geologist it may to a considerable extent take the place that H. B. Woodward's *Geology of England and Wales* used to occupy, though it is entirely different in conception and execution.

Useful bibliographies are appended to each system. They vary in completeness, and most of them seem to end about 1912; but some include references to papers published in 1913 and 1914. Most of the figures are from previous publications, but some of the maps and diagrams have been specially prepared. All of them are clear and well reproduced. One of the original maps is here reproduced on a reduced scale. A first glance revealed rather a large number of misprints, but this must have been by chance, for closer examination showed that the proportion of printers' errors is small. There is, in fact, no fault to find with the manner in which the book has been produced, and both editor and publisher may be congratulated. It should perhaps be added that the volume is in English. The price given on the cover is 16 marks, but what that may mean now no one but the publisher is likely to know.

P. L.

THE INFLUENCE OF MAN ON ANIMAL LIFE IN SCOTLAND: A STUDY IN FAUNAL EVOLUTION. By JAMES RITCHIE, M.A., D.Sc., F.R.S.E., Assistant Keeper in the Natural History Department of the Royal Scottish Museum. pp. 550. Cambridge University Press, 1920. Price 28s. net.

THIS book makes a strong appeal to the naturalist and the archæologist, as well as to all who are interested in the early history and development of Scotland. The author selected that country as the basis of his investigations, not simply because it lay close at hand and afforded comparatively easy opportunity for study, but for the far more important reason that Northern Britain, when the ice-sheet which exterminated all animal life receded, was not subjected to disturbing factors which elsewhere have complicated the problems of interaction between different groups of organisms and their environment. Dr. Ritchie draws an instructive and fascinating picture of the rich Scottish fauna which existed in the time when post-Glacial man arrived after the old Stone Age of England. He describes the reindeer and elk and the other kinds of deer, all of gigantic size as compared with their living representatives, the wild horse, ox, sheep, and boar, the lynxes, bears, and wolves, and many other species which have long since been exterminated by man. He presents evidence as to the origin and history of the domestic animals as well as other information of interest to the geologist; in particular we must mention the account he gives of the lower and upper forests of the peat. The book is enriched by some of Dr. Ritchie's own observations, as where he describes the remains of the cat dug up at Dunagoil, in Bute. (Since there was a pre-historic settlement there, could this animal have belonged to a domesticated variety?) The bones found were much larger than those of the modern wild-cat, and the inference is that this animal, like so many Scottish species, has diminished in size as man's influence increased. The book contains a wealth of information admirably presented, and the illustrations, some of which are by the author himself, are of a high order of excellence. There are also some useful maps, showing the distribution of certain animals at different historical periods.

F. H. A. M.

DIE STÄMME DER WIRBELTHIERE. By O. ABEL, Professor of Palæobiology at Vienna. xviii+914 pp., with 699 figures. Berlin and Leipzig: W. de Gruyter & Co. 1919. Price 56 marks unbound, 62 marks bound.

THIS work is primarily a textbook of vertebrate palæontology, but recent forms are referred to for purposes of comparison and classification. The book opens with a table setting out all the extinct and living families, and the classification here adopted is followed throughout the work. There is a short introduction dealing with various theoretical considerations and the meaning of

the terms "species", "variety", etc. This is succeeded by remarks on the anatomy and on the physiological significance of the skeletal structures with their primitive relations. The classification differs considerably from that of Smith Woodward. Thus, excepting for the Cyclostoma, all the primitive vertebrates (Osteostraci, Antiarchi, etc.) are included among the Pisces. *Palaospondylus gunni* is regarded as a larval Arthrodiran (perhaps *Coccosteus*) of Dipnoan affinities. The classification of some of the higher forms is apt to be conservative, and the Anomodonts are included among the Reptilia. It is to be regretted that some of the recent South African work on this subject was published too late to be noticed. It is a pity also that the scope of the book did not admit of discussions on the multiple origin of some of the domestic animals, for the phylogenetic development of these is hardly touched on. British authorities are, however, freely quoted, and most papers published up to the time of the War are duly referred to. The value of the work is enhanced by the inclusion of accounts of the author's own investigations on the Sirenia and Cetacea. The figures are both numerous and in the main excellent, and a number of these are from English sources, which are duly acknowledged. In view especially of the difficult conditions under which the book must have been completed, its issue is a great credit both to author and publishers. There are four valuable indices, of morphological terms, of classes, orders, etc., of genera, and of authors quoted.

F. H. A. M.

REMINISCENCES OF MY LIFE. By HENRY KEEPING. Second edition. pp. 24. Printed and published by F. W. Talbot, 17 Sussex Street, Cambridge. Price 2s. 6d.

IN reading these "Reminiscences" our regret is that they are not longer. Written by a geologist who has lived under five reigns, who was for nearly half a century Curator of the Museum of Geology at Cambridge, and who has spent much time in the company of distinguished men, this little work possesses a deep human interest. Mr. Keeping begins by telling us of his early life in the region of the New Forest and the Isle of Wight; he describes how he first came to study geology, and how his interest in the subject grew and was strengthened by those who became his friends. We get glimpses of great geologists long since departed, as well as reminiscences of other famous men, such as Dr. Whewell, Professor Henslow, and Sir Richard Owen, and we read how the author as Curator of the Museum came into close touch with Adam Sedgwick, the Woodwardian Professor, concerning whom he narrates some amusing anecdotes. Of the great amount of work which Mr. Keeping has done, we are able to form a slight idea, and we could have wished for a less fragmentary account of his numerous investigations in the field. Nevertheless, we are grateful to him for this interesting record of some of the incidents of his busy life, and we hope that in a third edition he may tell us more.

F. H. A. M.

REPORTS AND PROCEEDINGS.

EDINBURGH GEOLOGICAL SOCIETY.

November 17, 1920.—Mr. E. B. Bailey, M.C., B.A., F.G.S., F.R.S.E.,
President, in the Chair.

“Recent Advances in Highland Geology.” An Address by the
President, Mr. E. B. Bailey, M.C., B.A., etc.

There is good reason to believe that the rocks of the S.W. Highlands are assignable to three major structural divisions, which in descending order are as follows :—

Loch Awe Nappe.

Islay Nappe.

Ballappeil Foundation.

The Loch Awe Nappe is only preserved in the heart of the Loch Awe Syncline.

The Islay Nappe outcrops in the Islay Archipelago and in the district reaching from Kintyre to Loch Tay. The connexion between these two outcrops is locally severed by the Etive Granite.

The Ballappeil Foundation emerges from beneath the Islay Nappe in an extensive district ranging N.E. from Lismore and Glen Orchy. It takes its name from Ballachulish, Appin, and Loch Eilde.

The two lower structural divisions are themselves structural complexes. Thus a great recumbent fold has been recognized in Ben Lui within the limits of the Islay Nappe. This Ben Lui Fold, with an associated thrust at the base of the overlying Loch Awe Nappe, leads to a marked contrast of the two flanks of the Loch Awe Syncline below the level of the Ardrishaig Phyllites.

The Loch Awe and Islay Nappes seem to have travelled into position from the N.W. The reverse movement, so well known in the N.W. Highlands, is, however, exemplified by later disturbances, including the Loch Skerrols Thrust of Islay.

The interpretation of the S.W. Highlands, as sketched above, has much in common with Clough's reading of the Cowal district, which itself constitutes an important part of the region considered.

LIVERPOOL GEOLOGICAL SOCIETY.

November 9, 1920.—W. T. Walker, Esq., B.Sc., F.G.S., in the Chair.

Paper: “A Contribution to the Microscopic Study of the Carboniferous Limestone of North Wales.” By T. A. Jones.

The Carboniferous succession in North Wales is probably unrepresented by any beds earlier than those of the Upper Seminula zone. The limestones are almost entirely of organic origin, and are built up of the remains of crinoids, corals, polyzoa, foraminifera, brachiopod and other shells, cemented by a varying amount of clear secondary calcite. Occasionally some of the beds consist

almost wholly of one ingredient only, and may be crinoidal, coralline, polyzoan, or foraminiferal. The problematic organism, *Calcisphæra*, is found throughout the series, and sometimes occurs so abundantly as to form a substantial proportion of the mass of the rock. Small detrital quartz grains are rarely absent, and at times the quantity is so great as to give an arenaceous character to the beds. The insoluble residues consist in great part of tiny bipyramidal crystals of quartz, which have not been observed to have grown around worn grains. but in some cases growth in two stages is indicated by a perfect zonal structure. *Endothyra* are the principal foraminifera, occasionally forming the principal bulk of the rock. *Valvulina* and *Archæodiscus* are very common, particularly in the Upper Grey beds, and *Textularia* and *Trochammina* are also frequently met with, while *Nodosaria* is always extremely rare.

Oolitic limestones are seldom found, and seem to be confined to the Lower Brown and Upper Grey beds near Denbigh and Gwaenysgor, in Flintshire. Dolomites also are not very widespread, and occur principally in the Lower Brown, where they appear to be of subsequent origin, being associated with mineral veins and fault fissures. Calcareous algæ, again, although not entirely absent, seem to have played a negligible part in the building up of the rocks. It would appear, therefore, that the lagoon conditions which were so prevalent in South Wales and also in the North-West of England, were not characteristic in anything like the same degree of the North Wales area, although the limestones must have been deposited for the most part in quiet, shallow waters. It is not improbable that they were accumulated in an island-studded sea, on an uneven floor (for the various beds do not seem to have any great lateral extent), and not far from a low-lying mainland, which for the greater part of the period contributed very little sediment. The Middle White Limestones, which are much more massive and uniform in character than the beds above and below them, represent deeper water conditions. They are generally of great purity, the percentage of CaCO_3 often approaching 99.

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FEBRUARY, 1921.

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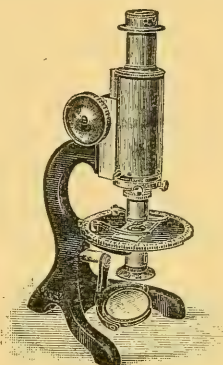
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Palæontographical Society.

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THE
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EDITORIAL NOTES.

THE Council of the Geological Society has this year made the following awards: Wollaston Medal (in duplicate), Dr. John Horne, F.R.S., and Dr. B. N. Peach, F.R.S.; Murchison Medal, Mr. E. S. Cobbold; Lyell Medal, Dr. E. de Margerie, Director of the Geological Survey of Alsace-Lorraine; Bigsby Medal, Dr. L. L. Fermor, Geological Survey of India; Wollaston Fund, Dr. T. O. Bosworth; Murchison Fund, Dr. A. Gilligan, University of Leeds; Lyell Fund, Professor H. L. Hawkins, University College, Reading, and Mr. C. E. N. Bromehead, H.M. Geological Survey.

* * * * *

THE following eminent geologists have been elected Foreign Members of the Geological Society: Dr. F. W. Clarke, Washington (D.C.), U.S.A.; Professor E. Haug, University of Paris; Professor M. Lugeon, University of Lausanne; Professor H. Schardt, University of Zürich; Dr. J. J. Sederholm, Director of the Geological Survey of Finland; and Dr. H. S. Washington, Geophysical Laboratory, Washington (D.C.), U.S.A. At the same time Foreign Correspondents were elected as follows: Professor L. Cayeux, Paris; Dr. M. Cossmann, Paris; Professor H. de Dorlodot, Louvain; Dr. H. Douvillé, Paris; Professor L. Duparc, Geneva; Professor J. Kjaer, Kristiania; Professor W. Lindgren, Boston; Professor J. J. Stevenson, New York.

* * * * *

THE science of mineralogy has suffered a severe blow by the death on January 6 last of Sir Lazarus Fletcher at Grange-over-Sands, where he went to reside on his retirement from the Natural History Museum less than two years ago. A memoir and appreciation of his work will appear in our next number.

* * * * *

THE Council of the Geologists' Association has this year presented the Foulerton Award to Mr. Llewellyn Treacher, F.G.S., who has been an active member of the Association for twenty years, and has conducted numerous excursions to places of interest in Berkshire and Oxfordshire, which counties have been the scene of the greater part of his original work.

ORIGINAL ARTICLES.

The Glaciation of Ireland.

By PERCY F. KENDALL.

DURING the year 1920 two contributions on the subject of Irish Glacial Geology have appeared, differing greatly in scope and treatment. Mr. Wright's paper on "Minor Periodicity in Glacial Retreat" is frankly speculative, but his speculations are based upon an accurate and fairly exhaustive survey of the glacial evidences in the country about the head of Kenmare River, the deep ria lying between Bantry Bay, Dingle Bay, and the lake region of Killarney.

The phenomena of which an interpretation is attempted belong to a late stage of the glaciation of the West of Ireland when the ice had shrunk back from the central plain and was apparently reduced to a series of independent systems of glaciers radiating from centres only a few miles from the seaward ends of certain of the rias.

Of all the other districts that have been studied none seems so remarkable and anomalous as this. The author shows by a map (fig. 1) the direction of ice-flow, from which it appears that the radiant point whence the ice flowed in every direction was not, as might have been expected, the lofty hill cluster of Macgillicuddy's Reeks culminating in Carruntuohill, 3,414 feet high, but either in the bed of the ria itself or in the low hills 1,100 to 1,300 feet high that lie along its northern shore. From this centre the passes through the Reeks were over-ridden, only the higher summits rising as nunataks above the ice.

The cause of this astonishing phenomenon has never been discussed—perhaps not even considered—but it is to be hoped that light will be thrown on the problem in the promised general memoir on Kerry. No doubt the mere fact that the last remnants of the great ice-sheet lingered in the west finds a ready explanation in the present meteorological conditions, the mountainous margin inducing copious precipitation; the problem is, however, to explain why, with a broad valley opening directly upon the coast and a dwindling mountainous margin on each side, the discharge should have taken these inland courses instead of flowing freely into the Atlantic. The temptation to invoke differential earth movement is checked by the reflection that lake-terraces extending for 12 miles "show no departure from horizontality which is not included within the limits of error inseparable from such observations of level as it has been found possible to make".

Mr. Wright describes this lake that occupied the upper part of the Kenmare Valley in considerable detail. It was held up by the ice to the level of the col at Morley's Bridge 320 feet O.D., and at this

level on both sides of the valley extends a beach rivalling the famous Parallel Roads of Glen Roy.

The materials of the beaches were, according to the author, supplied by marginal streams flowing along the edge of the ice, and for this reason a tributary valley has developed a terrace only on the west, that is the ice-ward, side.

The phenomena to which the title refers are a series of crescentic moraines—gravelly or sandy where below the lake-level, mainly clayey above. These occur on two scales of magnitude—larger moraines at intervals of about a mile and, above the lake-level, minor ridges at intervals of 50 to 100 yards. Mr. Wright ventures the suggestion that these correspond respectively to Brückner's thirty-year cycle of glacial fluctuations in the Alps and to the annual retreats established by de Geer's study of the nodes in the eskers studied by him in connexion with his seasonal clays, two layers of the clay representing a year's retreat. Mr. Wright finds confirmation of this view in the successive knobs of an esker close to Kenmare. The esker is about 600 yards long, and contains seven or eight of these hillocks. "The rate of retreat thus indicated is about 80 yards per annum."

The author applies similar methods to the great morainic amphitheatres near Killarney and Killorglin, from which he draws analogous deductions.

While the generalizations of the author of this paper may strike some as being rather too bold, it must be borne in mind that Glacial Geology has gone far beyond the stage when mere accumulation of undigested and unrelated facts should be recorded, and whether the time estimates suggested by Mr. Wright are accepted or not, he has indicated to British geologists a new method of inquiry that will certainly yield results of great interest and importance.

Of Professor Gregory's paper entitled "The Irish Eskers",¹ it is difficult to express my exact sentiments, for, despite the dignity of the *Philosophical Transactions* quarto, I feel that it does less than justice to the subject, to the author's position as a geologist, and to the large public to which his writings appeal. Of new field observations there are very few, and those few are susceptible of other interpretations than those the author puts upon them. The citations of the literature of British Glacial Geology are almost confined to a bygone generation; and the illustrations, where original, rarely exhibit features that are truly diagnostic, while in more than one instance the text is directly contradictory of the figure. The proposition which the author sets out to establish is that, contrary to the opinion expressed by Professor Sollas in his well-known memoir, the Irish eskers are mainly marginal—a species of well-washed bank laid down parallel to the edge of a dwindling ice-sheet that terminated in a rather shallow sea. Others he regards as the

¹ *Phil. Trans.*, ser. B, vol. cex, pp. 115-51.

products of glacial rivers, but he combats the opinion that they were laid down either beneath the ice or in ice cañons. Some arguments are advanced which will perhaps be accepted as sound, but, before Professor Gregory's views can be generally adopted, I feel that the subject must be approached with much greater deliberation and with a much fuller knowledge both of the facts already recorded and of Irish geology than he at present possesses.

It is obvious, as the author himself remarks, that "The first test, whether the eskers were due to sub-glacial rivers or were deposited as marginal banks, is the sources of the esker materials", yet he has made no attempt whatever to accumulate this vital evidence beyond a very few casual references; nor has he even used the data already provided by the Geological Survey and by other workers. In some instances these would support his conclusions, but in others they are in entire contradiction; for example, the ridge near Barony Bridge is thus alluded to by him under the heading "The Eskers of Tyrone": "has obviously been formed as a marginal formation by a glacier flowing northward and north-westward from Evishanoran Mountain." Dr. J. K. Charlesworth, on the other hand, informs me that the ridge in question was certainly laid down by ice moving *from* the north-west, and that it is full of the Tyrone granites.

In another case I think Dr. Gregory is right in spite of himself; his fig. 9 is a map showing the Esker System near Dunmore, co. Galway. Of this he says: "The distribution of the erratics, the direction of the striæ, and the trend of the drumlins show the main flow of the ice was from north-west to south-east." Now, the only mention of erratics is a casual reference to black chert, which has no bearing on the question, as it might have come from any point of the compass; no information whatever is vouchsafed regarding the drumlins, and it is amazing, but true, that the striæ are indicated on the maps by arrows "after Sollas" which show "the course of the ice-movement" to be, as Sollas explicitly declares, "from south-east to north-west"!

Another, and in many respects more serious, defect is exhibited by a sketch-map (fig. 11), in which "the broken arrows represent the course of the ice-movement after W. B. Wright". The first objection to this is that Wright's fig. 27 in his valuable *Quaternary Ice Age* shows "the lines of ice-flow and limits of glaciation in the British Isles" obviously, by the words just quoted, *at the maximum*, and therefore quite inapplicable to the late stage of shrinkage and retreat represented in Professor Gregory's view by the eskers. But, worse than this, a minute sketch-map one inch in breadth is enlarged up to the full breadth of a quarto page; and, worse still, the enlargement has been so badly done by the artist that arrows have been swung round through angles of 20-40 degrees. This carelessness or unskilfulness might in some cases have been immaterial, but as, for instance, an arrow passing through Carrick-

on-Shannon is made, to swerve round the *west* side of the Slieve Bloom Mountains, instead of, as Wright represented it, down the *east* side near the famous Maryboro esker, the error is perhaps accountable for Professor Gregory's mistaken supposition that this esker was "probably formed by ice which flowed down the northern slopes of the Slieve Bloom Mountains". He might have been spared this mistake had he consulted the Geological Survey memoir explanatory of Sheets 117-18 of the year 1866, which states that boulders of the Galway granite "are not so large or abundant on the northern as on the southern slopes of the Slieve Bloom Mountains". The Roscrea esker is by Professor Gregory included in the same explanation, but unfortunately it is not at the northern end of the mountains but a few miles south-west of the southern end.

Professor Gregory insists that the eskers were formed under water, and he assigns an arbitrary limit of 400 feet as the water-line, though in order to do this he finds it necessary without other apparent justification to put the Tyrone ridges in a separate category.

The question whether this was lake or sea he decides in favour of the sea, remarking: "The difficulty in the assumption of a glacial lake is to account for the containing barriers." Without labouring the point, I would say that the interpretation of Irish glacial geology adopted by all recent workers, except Professor Gregory, would without much difficulty provide him with the barriers he would need.

Having settled the marine origin of the eskers the author proceeds to disclose a remarkable and hitherto unsuspected change of opinion on the part of the British glacial geologists. He says (p. 145), "Some submergence of the British area during Glacial times is now generally accepted." Again, on p. 148, "It is now generally agreed that large parts of the British area were submerged in Glacial times to a sufficient height to have flooded the typical esker district of Central Ireland." And finally, with still greater courage, "Boulder-clay, the marine origin of which has been persistently maintained in spite of the rejection of that view by, at one time, the great majority of British glacial geologists." The implications here, and especially in the last quotation, are that a great and hitherto undisclosed revulsion of opinion has taken place, and that in common with the author, who has been sound throughout, the great majority of British glacial geologists no longer reject the marine origin of boulder-clay. If this is the case, then I can only say that it is the best-kept secret in geological literature. Where are the signs in the Q.J.G.S. or the GEOLOGICAL MAGAZINE of this change of opinion? Who are the recusants? I do not think they are to be found in our University chairs or in the Geological Survey, and certainly not in those of Ireland.

Though the context shows clearly enough that Professor Gregory intends a general assertion of the marine origin of all boulder-clay, I do not think he sufficiently realizes that if he and the "hidden

hand " are in the right, not only a part but the whole of the glacial geology built up by patient labour of investigators from 1872 onward is wrong, and floating ice must resume its place—our moraines, our glacier lakes, our unglaciated areas, all, all must go. And how does Professor Gregory proceed to make good his case? First, as to the Central Plain, by an appeal to the evidence produced three-quarters of a century ago by Oldham, supplemented a quarter of a century later by Kinahan, of the occurrence of shell fragments at several localities, and one single shell identifiable by name (*Buccinum undatum*) from an esker at Moate. The whole evidence has been sifted again and again by Irish geologists, only to be rejected. In the Dublin memoir Mr. Lamplugh states explicitly the several grounds upon which the Geological Survey rejected the marine hypothesis, and Professor Gregory should surely make some attempt to answer these arguments before he undertakes to reinstate it in geological literature. Professor Gregory contributes one solitary discovery of his own of a reputed marine organism in an esker, to wit, lobate calcareous incrustations upon boulders, one of which he submitted to Madame Lemoine, of Paris, who identified it as a *Lithothamnium*, a genus of calcareous algæ, enormously abundant in the Polar seas. It would be interesting to learn how many specimens were sent, and whether any were incrustations of the inorganic type that are very common in limestone gravels; and also whether Madame Lemoine was familiar with the tufa-invested pebbles that are found in streams in limestone countries.

Professor Gregory also found minute calcareous tubular incrustations—by the description, much resembling those due to deposition round roots—upon pebbles, and though Sir Sidney Harmer declined to admit their Bryozoan nature Mr. Alex Gray formed a different opinion. Dr. Gregory, however, considers that in view of Sir Sidney's adverse verdict judgment should be suspended. To account for the extreme rarity of fossils in eskers, Dr. Gregory adopts Kinahan's suggestion that in coarse gravels shells would not easily escape removal by solution. On this point an observation by Professor Sollas is valuable. He says that he and Mr. Praeger "were persuaded that it only required careful search to discover traces of marine organisms [in the Maryboro esker]; we searched intently from early morning to late evening, but without success; not a trace of a shell rewarded our efforts, and this notwithstanding the favourable character of much of the material composing the esker, which from its fineness and somewhat argillaceous nature was well fitted for the preservation of fossils had these at any time been present". Luck was clearly against them, for Kinahan found "a few small fragments of broken shell".

But how does Professor Gregory escape the dilemma which the admitted rarity of marine organisms in the eskers presents? He relies upon the supposed poverty of life in an ice-covered sea and supports the proposition by a judicious selection of extracts from records of

Polar exploration, almost every one of which can be answered from the same source thus—"as was pointed out by Brown (Quart. Journ. Geol. Soc., vol. xxvi, pp. 638, 688), many parts of the Greenland fiords, owing to the disturbed and muddy condition of the water, 'are bare of marine life,' and 'unfavourable for sea-animals'"; but Brown is also emphatic in declaring the richness in fossils of some of the fiord muds, and he follows the words just quoted by this remark: "Accordingly, if the bed of the Arctic Ocean in these places were raised and we found the mouth of a valley with laminated beds of clay rich in Arctic shells . . ." Professor Gregory's own experience in Spitsbergen refutes the suggestion he now puts forward, no less than does the testimony of Cole, Lamplugh, and others to the abundance of shells in the mud-bank at the snout of the Sefström glacier.

The citation of Nansen for the poverty of plant-life in the Arctic Sea where ice-covered and the rarity of Foraminifera in the plankton loses its significance when confronted with the following excerpts from vol. v of the report of his expedition: "*Globigerina bulloides* exists in great quantities and varying size in the great depths of the Polar seas." In "all the plankton samples taken later during the expedition there is quite an abundant animal life". Professor Gregory's comment that "The poverty of plant-life involves the rarity of animal life" is contradicted by Gran, who says, in the same volume, "It is difficult to understand how all the crustaceans (*Calanus finmarchicus*, etc.) that swarm in the upper strata can find the means of sustaining life." Mr. James Murray, of the first Shackleton Antarctic expedition, is quoted as saying: "On the shore there is no vestige of marine life, animal or vegetable, such as is found in the littoral zone of other coasts." Place against this the description by Professor David and Mr. Raymond Priestley of raised beaches, e.g. "But perhaps the most interesting feature of this deposit was the presence of hundreds of small shells", and again, "In the gravels and muds [in the Dry Valley of the Ferrar Glacier] up to a height of 50 feet fragments and whole shells of *Pecten colbeckii* and the same *Anatina* previously mentioned were very common, hundreds of fairly perfect shells being collected . . . the beach on which they occurred was two or three miles long."

In another place Professor Gregory alludes to the work of Mr. Joseph Wright, of Belfast, as showing the boulder-clay "to contain widespread indigenous foraminifera". The word "indigenous", of course, begs the whole question, the fact being that along a narrow belt of the east coast of Ireland the boulder-clay contains Foraminifera, among which *Nonionina depressula* greatly predominates, but *there are also species of exclusively Liassic or Cretaceous range*. Which are the true indigenes?

One may also fairly ask another question. Why has no one, neither Professor Gregory in his flying traverses nor the investigators resident in Ireland, ever found a shell or even some of Kinahan's

“small fragments of broken shell” in the boulder-clay of the Central Plain, of which some thousands of square miles was, according to Professor Gregory, occupied by the Esker Sea, with a maximum depth of over 60 fathoms?

Just as he fails to realize the full consequences of his dictum regarding the marine origin of boulder-clay, so equally he overlooks all that is implied by his 400 feet submergence. Perhaps he will permit me to supply the omission by the convenient method of comparison with an area where the conditions his hypothesis requires were most exactly paralleled. I allude to the Baltic area—here, according chiefly to Brögger for Norway, de Geer for Sweden, and Sederholm for Finland, the shrinkage of the great ice-sheet of North-West Europe coincided with a depressed condition of Fenno-Scandia, so that the ice deposited its great moraines the Ra, or the Salpausselka, with which our author specifically compares the Irish eskers, under the waters of a greatly enlarged Baltic, in which finely laminated muds, the “varviglera” of de Geer, were laid down. Apart from the interest of de Geer’s ingenious use of these seasonal clays for the purpose of a time scale, the deposits are invaluable for the information they yield, both in Norway and Sweden, regarding the biological or ecological conditions of a sea extraordinarily like that postulated by Professor Gregory. The muds, sands, and gravels are by no means sterile, but over large areas yield a rich, abundant, and well-preserved fauna of truly Arctic types. The level indicated by the deposits at the best-marked stage is almost exactly that assumed by Professor Gregory, namely 135 metres. Is it too much to ask for even a single shelly deposit in the Irish plain comparable with those Brögger has described?

I have had some opportunity of examining sections in many parts of Ireland during the past ten years, yet I have nowhere, except near Belfast, found anything in any degree comparable with these truly marine deposits; on the contrary, the boulder-clays, such as that covering the glaciated pre-Glacial beach in Ringabella Bay, co. Cork, are, as a rule, wholly devoid of the least semblance of lamination or bedding, and the materials, mud, sand, and stones, are confusedly intermingled in a fashion quite incompatible with deposition in water.

To conclude, the memoir seems to me so deficient in observational basis, and the far-reaching implications so generally ignored, that, attractive as the main proposition may seem, it should be regarded merely as an ingenious guess, in support of which evidence might well be sought by some geologist having time and inclination to make a methodical and persistent attack upon the problem.

Note on a Collection of Echinoids from the Limestone-lenticles in the Sand-pits of Shenley Hill.

By HERBERT L. HAWKINS, D.Sc., F.G.S., Professor of Geology,
University College, Reading.

AT the request of Mr. H. Woods, F.R.S., I have examined a small series of Echinoids belonging to the Sedgwick Museum, Cambridge, collected by the late J. F. Walker from the sand-pits on Shenley Hill, near Leighton Buzzard. Mr. G. W. Lamplugh has sent me four additional specimens from the same locality. The matrix seems to be the same in all the examples except D, and agrees absolutely with a sample of the Limestone-lenticles sent for comparison by Dr. F. L. Kitchin. The age of this Limestone is a subject of controversy (see GEOL. MAG., January–March, 1920), and a critical analysis of its fauna seems the only means of deciding the issue. Unfortunately, most of the Echinoids are very indifferently preserved so that specific determination is often doubtful, and in some cases impossible.

Twenty-four specimens were submitted to me by Mr. Woods, and I have placed numbers on the boxes in which they were sent. Under those numbers they are referred to here. The following is the list according to my determinations:—

1. Internal mould of ? *Peltastes* or ? *Salenia*.
2. Internal mould of ? *Pseudodiadema* or ? *Diplopodia*.
3. "*Pyrina*" sp. nov. (? nov. gen.).
4. *Pyrina* sp.
5. Internal mould of *Pyrina* sp.
6. *P.* cf. *inflata* d'Orbigny.
7. *P.* cf. *desmoulinsi* d'Archiac.
8. *P.* cf. *desmoulinsi* d'Archiac.
9. *P.* aff. *lævis* Agassiz.
10. *P.* sp. (or spp.). Two specimens.
11. *P.* aff. *lævis* Agassiz. Two specimens.
12. *P.* aff. *lævis* Agassiz.
13. *Catopygus columbarius* Agassiz. Two specimens.
14. *Nucleolites lacunosus* Goldfuss.
15. "*Echinospatagus*" aff. *murchisonianus* (Mantell).
16. Internal mould of ? *Cardiaster* or *Holaster*.
17. Internal mould of ? *Cardiaster* or *Holaster*.
18. Indeterminable Echinoid fragment.
19. *Cardiaster* ? *latissimus* Agassiz.
20. *C.* cf. *fossarius* (Benett).
21. *C.* cf. *fossarius* (Benett).

Mr. Lamplugh's specimens are —

- A. Internal mould of *Pseudodiadema* (? No. 2 above).
- B. Obscure specimen (? same form as A).
- C. ? *Cardiaster* sp. Two very small specimens.
- D. Mould and counterpart of *C.* aff. *latissimus* Agassiz (see note below).

A few critical notes on some of the specimens are now given, and apologies are due for their scanty character; but pressure of academic work denies opportunity for prolonged research at the

present time, while delay in publication of the report would in some measure defeat the object in view.

3. "*Pyrina*" sp. nov. This is a remarkable and fairly well-preserved specimen, which I am unable to refer to any form hitherto described; it is improbable that it can belong to *Pyrina*, however that genus be interpreted. At first sight it gave the impression that another specimen of the rare *Hoelectypus bistriatus* Wright had turned up; even now it is impossible to examine it without recalling *H. hemisphaericus* from the Inferior Oolite. However, the characters of the apical system, tuberculation and adoral surface show clearly that it possesses more attributes of the ill-defined series usually called *Pyrina* than of the *Hoelectypidæ*. The inflation of area 5 between the periproct and peristome is the only superficial feature distinguishing the form from an *Hoelectypus* with marginal periproct, for the peristome is not displayed. While convinced that the species is undescribed, I prefer to await opportunity for figuring and fully analysing it before giving it a name. This I hope to do in the course of a few months.

4. *Pyrina* sp. This ill-preserved specimen agrees in proportions with the Senonian species *P. atacica* Cotteau, but shape is an almost valueless feature in specific determination of the Echinonëidæ. No. 5 is probably the same form.

6. *Pyrina* cf. *inflata* d'Orbigny. A thick, subglobular *Pyrina* that may be a truncated variety of this Cenomanian species.

7 and 8. These are both rather broader than typical specimens of *P. desmoulinsi*, but otherwise seem to agree with that species.

9. *Pyrina* aff. *lævis* Agassiz. Undoubtedly the form so named by Wright. Both specimens under No. 11 are similar in proportions, while No. 12 (the best-preserved specimen in the collection) is again Wright's *P. lævis*.

4-12. It may be remarked that all the specimens of *Pyrina* are probably shape-variants of a single species; the forms attributed to *P. lævis* being immature. Their range of variation is not so great as that shown in the modern analogue, *Echinonëus cyclostomus* Leske (see Westergren, 1911).

13. *Catopygus columbarius* Agassiz. There can be no doubt that the larger of the two specimens is a short form of this common species. The smaller one might be ascribed to *Caratomus*, but its bad preservation makes definite determination impossible. In either case no stratigraphical difference would be involved.

14. *Nucleolites lacunosus* Goldfuss. This is one of the few confident identifications in the series.

15. "*Echinospatagus*" *murchisonianus* (Mantell). A small, quite uncrushed specimen in which all surface ornament has been destroyed in extracting the test. The species to which it is referred is the only one to which it bears any resemblance, and the similarity is very close. I do not know the correct generic name for the form, so use that employed by Wright; there is no doubt as to the affinity

between the Shenley specimen and that figured in Wright's Monograph, pl. lxiv, fig. 1, but the former is slightly smaller.

16 and 17. These small internal moulds might be referred to *Cardiaster* or *Holaster* with equal reason. If they are *Cardiasters*, the nearest approach would be *C. benstedii* Forbes, from the Lower Greensand; if *Holasters*, *H. laevis* (de Luc) from the Cenomanian.

19—21. If shape is of any use in recognition of species of *Cardiaster*, the suggestions made seem the most reasonable; they are given without any real confidence.

The only specimens whose determination is sufficiently precise to afford safe stratigraphical evidence are Nos. 6—9 and 12—15. *Pyrina inflata* was described by d'Orbigny as occurring in the Cenomanian of Le Mans (Sarthe), where the general Echinoid fauna shows strong affinities to that of the "Top-beds" of the Upper Greensand. *Pyrina desmoulini* is characteristic of the "Chloritic Marl" and associated deposits. *P. laevis* is a "Warminster" species, probably from the highest beds or "Cornstones". *Catopygus columbarius* (and *Caratomus rostratus*) occur at the same horizon, and in the lowest part of the Chalk itself (sub-zone of *C. columbarius*). *Nucleolites lacunosus* occurs in the zone of *P. asper*, and ranges up into that of *Am. varians*. "*Echinospatagus*" *murchisonianus* is recorded by Jukes-Browne, in the Survey Memoir, from the zone of *Am. rostratus* (Malmstone) of Blackdown and Haldon. This summer I found it in abundant fragments at the last-named locality, always in the uppermost, chalcedonic beds. These have also yielded a mould of *Anorthopygus orbicularis*, a fossil familiar at Le Mans, so that they may well contain coastal deposits of "Chloritic Marl" age. *Cardiaster latissimus* is similarly recorded from the Malmstone, and in Western England has been found at Golden Cap (Dorset) *vide* Wright, in sands presumably equivalent, in part, to the Blackdown and Haldon beds.

All definite indications seem to point to an horizon roughly corresponding to the "Warminster top-beds" (of the Survey Memoir) for the Shenley Echinoids. It has been shown that a large proportion of the fossils recorded from Warminster were in reality collected from the "Cornstones" of adjoining districts, and so belong rather to the base of the Chalk than to the top of the Greensand. The outstanding feature is the relative abundance of *Pyrina*, about half of the specimens being referable to that group. This probably indicates local littoral conditions, since *Echinonæus*, the modern representative of the family, inhabits tidal flats. The absence of *Discoidea subuculus* from the collection is thereby made noteworthy, since that species is usually far commoner than any others in the zone of *P. asper*.

The only specimen in the collection referred to a species belonging to an earlier zone than that of *P. asper*, is "*E.*" *murchisonianus*. There can be no question as to the indigenous quality of the specimen; it is quite unbroken, and of too delicate a texture to have survived

much attrition; but, on the other hand, its specific identity is far from proved. With this possible exception there is nothing in the Echinoids to suggest that the limestone from which they came is older than the *P. asper* zone; while positive evidence (*C. columbarius* and *N. lacunosus*) and negative evidence (*D. subuculus*) agree in suggesting an horizon even higher than the uppermost Selbornian.

Note inserted in proof.—Mr. Woods has sent me six radioles of *Cidaris* from Shenley. Three of these certainly belong to *C. bowerbanki*, a "Grey chalk" species. The other three probably represent the same species. Dr. Kitchin has sent a specimen of ? *Cardiaster* or *Holaster* (Mus. Pract. Geol., Nos. WM 4741 and 4742) from the nodules in the *mammillatus*-zone near Leighton Buzzard. This specimen agrees exactly with No. D above, both in form and matrix. It is not specifically determinable.

The Interglacial Problem and the Glacial and Post-glacial Sequence in Northumberland and Durham.

By DAVID WOOLACOTT, D.Sc., F.G.S.

(Concluded from p. 32.)

THE features of the Glacial deposits and associated phenomena just discussed are in general so clear that most observers would arrive at the same conclusion regarding them, but there are some other features about which, either due to their controversial nature or the conflicting character of the evidence, there is not yet such general agreement. These are (a) the evidence for Interglacial Periods in the Drift of these counties, (b) the raised beaches of East Durham, (c) the origin of the leafy clays, (d) the explanation of the distribution of fragments of certain rocks—Flint, Chalk, Magnesian Limestone—in the Superficial Deposits.

1. The evidence for Interglacial Periods. In my paper on the Superficial Deposits of the Northumberland and Durham Coalfield, I state that "as far as the available evidence goes there does not seem to be anything pointing to an Interglacial Period or Periods",¹ and Dr. Smythe in his study of the Glacial Geology of Northumberland has evidently arrived at the same conclusion as regards the whole of that county, as he states that "No classification of the boulder-clays of Northumberland seems possible, though locally there is frequently evidence of two clays of different origin".² In his description of the glacial deposits of South-East Durham

¹ Quart. Journ. Geol. Soc., vol. lxi, 1905, p. 68. I also state that "some of the thicker deposits (of sand and sandy clay found intercalated in the boulder-clay) may represent epochs when the ice was melting quicker than others, but whether they can be considered in any sense as 'Interglacial' is very doubtful"

² *Glacial Geology of Northumberland*, op. jam cit., p. 93:

Trechmann has brought forward evidence in favour of an Interglacial Period between the deposition of the Scandinavian and the British (or Main) Drift, and has suggested a possible Interglacial episode between the formation of the boulder-clay with only western erratics in it, and the more northerly derived deposit with Scottish, Cheviot, and other rocks.¹

I have already discussed my views regarding the Interglacial controversy, and propose to examine the subject from the standpoint stated. The evidence for an Interval-in-the-Glaciation which may possibly be Interglacial in character between the Scandinavian and British Drift is much stronger than that for even a Glaciation-interval between the two British Drifts. The general sequence of the boulder clays in Northumberland and Durham stated by Dr. Trechmann is correct. Along the coastal region of Northumberland and Durham this sequence is (a) Scandinavian Drift, (b) Drift with western erratics,² (c) Drift with Scottish, Cheviot, and Western boulders. The Scandinavian Durham basement clay is overlaid by the Tweed-Cheviot-Lake District boulder-clay with Interval-deposits between at Warren House Gill; the evidence proves that the western-derived clay was deposited along the coastal region of South Northumberland, and was then removed by the southerly moving Tweed-Cheviot ice, hence the mixture of Lake District, Cheviot, and Scottish erratics along the Durham coast. Clay with only Lake District-Tees Valley boulders has been proved to occur in a depression at Hartlepool,³ and the western-derived clay can be seen under that from the north along the Northumberland coast between Bamburgh and the Wansbeck.⁴

The main difficulty in accepting that there was an Interglacial period between the deposition of the Scandinavian and the British Drift near Castle Eden is that the hypothesis seems to demand that there was no British ice on the east of Durham during any stage of this, the maximum, extension of the Scandinavian ice-flow. It seems hardly possible that this ice could occupy the greater part of the North Sea area, without there being a concurrent gathering of ice on the uplands of Scotland and England and therefore a flow at the same time across the North of England.⁵ It has always been

¹ Op. jam cit., 1920, p. 193.

² There is, however, distinct evidence that ice bringing Scotch erratics reached the Northumberland coastal region before that from the Lake District.

³ Trechmann, *Quart. Journ. Geol. Soc.*, vol. lxxv, pt. iii, 1920, p. 192.

⁴ Smythe, *Glacial Geology of Northumberland*, p. 94.

⁵ The difficulty introduced by this is seen when the Basement clay of Holderness and the Scandinavian Drift of Durham are compared. The former contains English and Scottish erratics mixed with foreign rocks ("Geology of Holderness": *Mem. Geol. Surv.*, pp. 18-19), the latter only such boulders as could be brought by the passage of an ice-sheet from Norway. The Durham Basement clay must therefore on this hypothesis belong to an earlier period of glaciation than that of Yorkshire with an Interglacial period (or possibly two such intervals between). This is, however, not impossible, but it is evident

generally agreed by European glaciologists, who accept a series of Interglacial periods, that the time of maximum extension of the Scandinavian ice or Second Glacial Epoch (Saxonian, J. Geikie) was contemporaneous with extensive glaciation in England.¹ This difficulty does not occur if the loess deposit is an "Interval-deposit" marking an "Interval-in-the-Glaciation", and I submit that while appreciating the strength of Dr. Trechmann's argument and admitting that his work has added considerable interest to the study of the glaciology of the north-east of England, until the evidence is more conclusive in the face of this difficulty it is better to regard it as such than as an Interglacial formation.

The evidence for an "Interval-in-the-Glaciation" between the Scandinavian and the British Drift is founded on (1) an Interval-deposit of loess, with its decalcification and the weathering of contained rocks, (2) the possible formation of a shore-line from which the shell-bearing materials of the Kaims were derived, and (3) the possible erosion of valleys in the interval. I propose to discuss this evidence briefly:—

(1) While admitting that the deposit at Warren House Gill is true loess and that it is an Interval-deposit of considerable interest, it may be doubted whether an Interglacial period is necessary to account either for its occurrence or the formation of concretions in it or the weathering of the contained boulders. Dr. Trechmann states that loess was formed on the edge of the advancing Scandinavian ice-sheet and was overridden and incorporated with the Drift.² May not therefore the deposit at Warren House Gill have been formed on the margin of the ice-sheet, before the oncoming of the British ice on to the area? If so, it does not seem to demand a prolonged Glaciation-interval to account for its occurrence. I have noticed in the local drifts (and some years ago carefully examined) small pockets and spreads of finely divided material, which I have always regarded as the silt of glacial streams, and it seems possible to me that this deposit of loess was formed on the edge of the ice-sheet from the rock-flour carried off by waters from the margin of the ice.³ From my observations of the quickness with which certain processes may take place, the decalcification of the loess and the formation of concretions in it, while strengthening the argument for an Interval of some duration, do not necessarily imply an Interglacial period. Decomposed boulders in the loess are also evidence in favour of an Interval, but again are not conclusive proofs of an Interglacial period. I have obtained from the

that the glacial deposits of North-East England will have to be critically re-examined if an Interglacial epoch between the Durham Scandinavian and the British Drifts is accepted as proved.

¹ J. Geikie, *Great Ice Age*.

² Op. cit., Quart. Journ. Geol. Soc., 1920, p. 176.

³ J. Geikie, Address to the Geol. Section of the Brit. Assoc., Newcastle, 1889, p. 19, where a similar view of the origin of the loess is given.

Scandinavian Drift a quite friable granite, and decomposed and weathered granites occur in other boulder-clays.

(2) Because of the less Arctic character of the fauna of the shell-bearing Kaims when compared with the Scandinavian Drift, Dr. Trechmann has suggested that the former were deposited on the edge of the Tweed-Cheviot glacier at a later period of glaciation than the maximum extension of the Scandinavian ice, an Interglacial shore-line having been formed during the epoch.¹ Arguments from derived faunas can never be very conclusive, as the shells in the Scandinavian Drift may not only have been brought from a greater depth than those in the Kaims, but they may also be from deposits formed at a different period. It is, however, probably from a consideration of the faunas in the different Pleistocene deposits in the north-east of England that the surest evidence is to be obtained as to whether the Glaciation-interval between the deposition of the foreign and British drifts is an Interglacial one. As the shell-bearing Kelsey Hill deposits² appear to have been pushed inland at the same time as the Durham Kaims were formed, i.e. the period when the Tweed-Cheviot and other ice was being forced along the coast, a comparison of the faunas in these two deposits would be of interest in connexion with this subject; and as there is a possibility that the Sewerby Raised Beach is an Interval-deposit, a comparison of its fauna with that of the Durham Kaims would be worth considering; indeed, it would be of value if complete comparative lists of the faunas of all the Pleistocene deposits in Durham and Yorkshire were published and critically examined, including the deposits mentioned and the Scandinavian Drift of Holderness (which may be of later formation than that of Durham), the Bridlington Crag, and the raised beaches of the Durham coast. If it can be proved that a shore-line with a temperate fauna was formed between the deposition of the Scandinavian Drift near Castle Eden and the British boulder-clays it would considerably support the argument for an Interglacial period having occurred between these formations.

In connexion with the material composing the Kaims there is one piece of evidence that might have been advanced in favour of the view that they belong to a later period of glaciation than the Scandinavian Drift, and that is that if a shore-line was formed it would have probably contained boulders of Scandinavian rocks derived from the basement Drift, and therefore the Kaims should contain such rocks. I have never seen any undoubted Scandinavian pebbles in the Kaims near Sunderland nor in the Sheraton mounds, but Trechmann records "a fragment apparently of a rhomb porphyry" from the latter.³ It would be of interest to know

¹ Op. jam cit., p. 189.

² *Geology of Holderness* (Mem. Geol. Surv.), 1885, p. 53.

³ Quart. Journ. Geol. Soc., vol. lxxi, pt. i, 1915, p. 74.

whether foreign rocks do occur in the Kaims in any quantity,¹ as if so it would undoubtedly lend support to the argument in favour of the formation of a shore-line, as the loose materials of such a deposit would be much more easily removed than the stiff Scandinavian Drift.

(3) It has also been suggested that the valleys of "Hesleden", "Castle Eden", and "Hawthorn", which are now filled with boulder-clay containing Scottish, Cheviot, and Lake District erratics, and which I have described as Preglacial, were eroded between the deposition of the Scandinavian and the overlying British Drift. I considered these valleys when I first described them to be mature Preglacial waterways, and I am not aware of any evidence which proves they were formed during an Interval-in-the-Glaciation or were modified in such a period. We cannot be certain that some of them do not contain Scandinavian Drift at their base,² and if it was a lobe of this ice that reached the Durham coast they may be Preglacial and yet not have foreign boulder-clay in them. These valleys should, however, be examined as opportunity permits for the occurrence in them of Scandinavian Drift, and for their possible formation during a Glaciation-interval.

It has been further suggested that there was an Interglacial episode during the deposition of the Main or British drifts. Trechmann has noticed the occurrence of clay filling a depression at Hartlepool, which contains only boulders brought from the west down the Tees valley; it is also possible that such western-derived drift may occur at the base of the Preglacial "Tyne" or "Sleekburn"; and Smythe has shown that in Northumberland, between Bamburgh and the Wansbeck, there are two boulder-clays, one mainly derived from the west and an upper with material from the north (Tweed valley, etc.). There are no Interval-deposits or other evidence in support of this suggestion, but it is quite possible that there is an "Interval-in-the-Glaciation" between the formation of these two drifts, as the supposed later glaciation which brought the material from the north was undoubtedly the greater, and so may

¹ Flint and Chalk are, as I shall show, so peculiarly distributed in the Superficial Deposits that I do not regard them as all having been brought by the Scandinavian ice to the area.

² About 1903 Mr. Bell, of Bishop Auckland, sent to me two or three small pieces of rock which he had obtained from material dug up in excavations in Castle Eden Dene. One was a fragment of Laurvik syenite. I visited the locality shortly afterwards, and decided that it had been obtained from a gravel deposit and not from boulder-clay. I did not, therefore, record it at the time. In 1910 I saw a boulder of Laurvik syenite cemented in the foot of the cliff north of Castle Eden near Warren House Gill, and at the same time saw other evidence—that Dr. Trechmann has since, along with much new material, fully described—which convinced me that the Scandinavian ice had reached the Durham coast and that the boulders were true erratics. I therefore recorded the boulders in the Boulders Com. Report of the Univ. Durham Phil. Soc. (Proc. Univ. Durham Phil. Soc., vol. iv, pt. ii, 1910–11, pp. 89–90) and in Proc. Geol. Assoc., 1912.

have removed all such evidence as well as the greater portion of the drift of the earlier period. The superposition of these two drifts is, however, quite explainable on the hypothesis of a continuous glaciation, without a Glaciation-interval or Interglacial period, as the ice-streams coming from the west may have reached the coastal region before they were diverted southwards by the pressure of the Scandinavian ice in one continuous glaciation; thus boulder-clay with western erratics would later be overlaid by drift containing northerly derived material. Further evidence would seem to be necessary before an "Interval-in-the-Glaciation" can be taken to be proved in the deposition of the purely British drifts of Northumberland and Durham.

In connexion with the Interglacial Problem there are three deposits of special interest apart from those already discussed. These are (1) the Sewerby Raised Beach near Bridlington, (2) the deposit at Horsebridge Head, north of the mouth of the Wansbeck, and (3) that at the Lyne Burn.

(1) Trechmann has stated that the evidence for the Preglacial age of the raised beach at Sewerby, near Bridlington, is not conclusive,¹ and if it is eventually proved that there are Glaciation-intervals in the formation of the Drifts of the North of England it would seem possible that it could have been formed in such a period.

(2) The gravel deposit at Horsebridge Head, which rests on the rock surface beneath boulder-clay,² has been thought by some observers to be a Preglacial raised beach³; but Dr. Smythe after a very careful examination regards it as the deposit of an early Glacial stream.⁴ The evidence obtained from an examination of the boulders is not conclusive. Chalk, flints, fossiliferous magnesian limestone, Cheviot porphyrite, igneous and metamorphic rocks all occur in it.⁵ Bullerwell also records a fragment of a shell (*Ostrea* ?) from it. There seems to be material from several sources, including Scotland, the Cheviots, the Magnesian Limestone (whose present outcrop is several miles further south), and from Cretaceous strata. It is rather a puzzling formation, but it certainly seems to afford evidence of a passage of ice from the north before the deposition of the more westerly derived boulder-clay overlying it, and it is possible that it is an Interval-deposit or even a true Interglacial bed.

(3) A deposit containing very much the same admixture of material, including greywacke and garnetiferous mica-schist (Pitlochrie ?), occurs a few miles to the north at the mouth of the Lyne Burn; it, however, rests on reddish prismatic clay below which is typical boulder-clay, and is covered by blown sand. This deposit again might

¹ Op. jam cit., p. 190.

² There is a photograph of this deposit in my paper on the Superficial Deposits, op. jam cit., p. 68.

³ e.g. Bullerwell, "Section of the Cliffs near Newbiggen by the Sea, etc.": Nat. Hist. Trans. Northumberland, etc., vol. iv, pt. i, 1914, pp. 61-6.

⁴ *Glacial Geology of Northumberland*, ibid., pp. 98-9.

⁵ Bullerwell regards some of the granites as being from Aberdeen.

be regarded as a raised beach, but Smythe considers it to be similar in origin to that at Horsebridge Head; pointing to a passage of ice from the north after the deposition of the western derived Drift. Is it possible that the Lyne Burn deposit is also an Interval- or Interglacial deposit? The critical examination of such beds makes the Drift of the north-east of England much more complicated than it at first appears to be.

2. In the papers on the Superficial Deposits and the Origin and Influence of the chief physical features of Northumberland and Durham, certain regularly-bedded shell-bearing gravels and sands occurring up to the 150-foot contour were described as raised beaches. Various arguments have been advanced by different geologists against considering these deposits as uplifted marginal sea-deposits, such as, they cannot be traced north of Tynemouth nor along the Yorkshire coast nor far inland, also that shell-bearing sands and gravels that have been carried inland by ice occur in Durham at a higher level; but all such arguments disappear before positive evidence obtained from an examination of the deposits. In the June number of the *GEOLOGICAL MAGAZINE* for 1920 there is described an exposure of these beds at Easington, from an examination of which it should be possible to definitely decide whether these deposits are raised beaches.¹ After the exact method of the formation of these sands and gravels has been agreed upon, their extent and peculiarities may be more fully discussed.

The submerged forests of the Durham coast rest on boulder-clay; that at Whitburn Bay is certainly formed from a growth of vegetation in situ. They appear to mark a slight recent depression, but there is the distinct possibility that their present relation to the sea-level is due among other causes to the slipping and settling down of the superficial deposits in the valleys and depressions in which these formations rest, and therefore that they do not mark any regional sinking of the crest.

The complex character of part of the Superficial Deposits in the north-east of England can be studied in the Tyne valley. These have been carefully examined by E. Merrick, who has worked out the sequence of the beds.² The Preglacial "Tyne" reaches a maximum depth beneath sea-level of 169 feet at Dunston, west of Gateshead, about 10 miles inland, while at its mouth it is only 141 feet. The slope of bed rock is of a switchback nature due to the formation of a series of rock basins along its course by glacial action. This old depression is partly filled by a series of deposits of very varying character, the exact origin of which is very difficult in some cases to determine. They probably include true glacial deposits of boulder-clay, fluvio-glacial beds, glacier-lake deposits, estuarine deposits (formed when the coastal region was embayed at the time of the

¹ I regard them as true Raised Beaches.

² "On the Superficial Deposits around Newcastle-upon-Tyne": *Proc. Univ. Durham Phil. Soc.*, vol. iii, pt. iii, 1909.

formation of the raised beaches), alluvial and land deposits, and are thus partly formed of thick deposits of reassorted glacial and other material. The leafy clays were deposited in tranquil conditions, and while they are usually regarded as glacier-lake deposits some of them may also be of estuarine origin. Merrick has found in these finely laminated clays numerous tracks of some forms of locomotive invertebrate life,¹ probably of annelids, as no fossils have ever been found in them, but some of the tracks are like those of crustacea or gastropods.

The sequence worked out by Merrick includes :—

Soil.

Yellow clay (weathers into short columns, prismatic clay).

Brown clay (stiff brown clay with boulders).

Rotten loam sand.

Common clay (roughly bedded boulder-clay).

Surface leafy clay.

Black clay (with striated and unstriated boulders).

Leafy blue clay.

Scarp (boulder-clay).

Sand.

Similar leafy and other clays are found in the Tees valley.² Sometimes in the leafy clays boulders are found, which would appear to have been rafted by ice or vegetation and dropped into the deposit.³

The distribution of most of the rock-fragments in the Superficial Deposits of Northumberland and Durham can be explained from the general trend of the ice-movements in the area, but that of some rocks, such as Flint, Chalk, and Magnesian Limestone, is so peculiar as to be worthy of special notice. While many of the positions in which pieces of these rocks occur offer no special difficulty some undoubtedly do, if we accept the hypothesis that the Chalk and the Flint were brought by the Scandinavian ice from the bed of the North Sea, and, in connexion with the distribution of the Magnesian Limestone, that the direction of ice-movement down the Northumberland coast was always from north to south. Flint occurs in the Scandinavian Drift at Warren House Gill, and in a comparatively stoneless clay resting on the boulder-clay at Trow Rocks, South Shields, and at Tynemouth (Howse's Scandinavian Drift). I have never seen it in, and I do not remember it having been recorded from the typical Main or British Boulder-clay in Northumberland and Durham, but it may occur. It is present in the deposits at Horsebridge Head, and at the Lyne Burn already noticed. It has been found in the Kaims and large rolled flints occur in the gravels and sands at Cleadon (Raised Beach). The late

¹ See photographs *op. jam cit.*, pl. i.

² Trechmann, *op. jam cit.*, 1920, p. 192.

³ See description of such a boulder by Professor Lebour, *Proc. Univ. Durham Phil. Soc.*, vol. ii, pt. ii, 1901-2, p. 81.

Professor Lebour informed me that several had been found near the surface on the Newcastle Town Moor. Chalk has a somewhat similar distribution,¹ but boulders of it (one striated) have been found in the boulder-clays of the Tyne valley at Walker and Heaton, near Newcastle, and I have found a small chalk pebble in gravels at Ponteland, several miles north-west of Newcastle. It is almost impossible to explain this widespread occurrence of these rocks on the generally accepted hypothesis of ice-carriage to the area. The distribution of Magnesian Limestone is also worthy of note, as it has been found at several places up the coast of Northumberland (Horsebridge Head, Lyne Burn, etc.) as far north as Amble, i.e. several miles north of its present outcrop; and boulders have also been proved to occur at Walker in the Tyne valley near Newcastle, some miles west of it. Are these fragments remnants of strata that once overlaid the area beyond the present outcrop of the Cretaceous and Permian strata?

If certain of the phenomena discussed in this paper have been correctly interpreted they appear to prove that definite changes of level have taken place in the north-east of England since the erosion of the Pre-glacial surface. The depressions in which some of the superficial deposits lie prove that prior to the Glacial period Northumberland and Durham were more elevated than at present; if an Interval- or Interglacial shore-line was formed during the early part of this epoch, then the area was only slightly above the present level when it was formed; while the Raised Beaches prove that the area was subsequently depressed and then uplifted. The latter movement was probably more pronounced along the coastal region of Durham. The depression since Pre-glacial times may have been the result of the load of ice which covered the country, and the uplift one of the results of its removal.

THE GLACIAL AND POSTGLACIAL SEQUENCE IN NORTHUMBERLAND AND DURHAM.²

	Formation of peat beds and submerged forests.
	Extensive erosion of the Drift along main superimposed valleys. Formation of river terraces and alluvial haughs. Deposition of thick beds of assorted Glacial material.
	Formation of lakes occupying rock basins, hollows in the Drift and amongst the Kaims.
Post-glacial.	Final erosion of Postglacial gorges of Wear, Wansbeck, Hawthorn, Castle Eden Dene, etc.
	Postglacial Tyne, Tees, and Upper Wear valleys superimposed on Preglacial valleys.
	Formation of marginal sea-deposits, followed by an uplift—maximum 150 feet—producing the Raised Beaches. Deposition of much material in Tyne valley—leafy clays, sands, etc.

¹ Has been recorded from the Horsebridge Head gravels, Lyne Burn deposit, from clays in the Tyne valley, from the Raised Beach deposit at Cleadon.

² This table is only intended to show the general sequence of events: there must have been considerable overlapping, but the general order in which they took place is considered to be something of this nature.

Glacial.

Disappearance of ice from counties.
 Retreat of ice from country until small glaciers occupied valleys in Cheviots and Lake District, etc.
 Final retreat of Tweed-Cheviot ice from coastal region.
 Deposition of leafy clays, etc., in the Tyne and Tees valleys in lakes held up by ice along coastal border.
 Formation of glacier-lakes in Mid-Northumberland and of associated Kaims and overflow valleys, when the Western ice had retreated and the Tweed-Cheviot still occupied the coastal border; concurrent formation of lakes in lower Teesdale and Weardale; cutting of Ferryhill Gap; commencement of erosion of gorges of Wear, Wansbeck, etc., by streams flowing from waters held up by ice.
 Formation of Grindon, Warden Law, and Sheraton Kaims on the margin of the Tweed-Cheviot ice occupying the coastal region of Durham.
 Glacier-lakes of Cleveland Hills formed during maximum pressure of the combined ice-sheets along the coastal region.
 Glacier-lakes formed in the higher regions of Teesdale, Weardale, and the Cheviots.
 Advance of Forth and Tweed-Cheviot ice and of Western ice across Northumberland and down Teesdale; all these streams were diverted southwards by the pressure of the Scandinavian ice-sheet.¹
Possible Interval in Glaciation.
 Advance of Western ice across coastal region.
Possible Interval in Glaciation. Possible formation of Horsebridge Head gravels as an Interval-deposit.
 Advance of ice from Scotland along coast of Northumberland.²
Glaciation-Interval. (Possible Interglacial Period, Trechmann.) Formation of Interval deposit of loess, etc. Possible formation of Interval shore-deposits and erosion of valleys.
 Advance of Scandinavian ice-sheet to Durham coast.³

Pre-Scandinavian { Deposition of Teglial, Cromerian, and other deposits on
 Drift ⁴ or the North Sea area.
 Preglacial. { Formation of Preglacial valleys of "Wash", "Tyne",
 "Tees", etc.

¹ and ³ If Interglacial Periods did not occur, then the Scandinavian ice must have occupied the North Sea area continuously during the glaciation of the two north-eastern counties. It was the first to reach the Durham coast, and the Tweed-Cheviot ice was held along this region by it until the retreat of the British ice had commenced. The Sewerby Raised Beach, the Horsebridge Head deposit, as well as the Interval-deposits given, may have been formed between 2 and 4. The Basement Clay of Holderness, if, as already suggested, it is not contemporaneous with the Durham Scandinavian Drift, may have been deposited and the Bridlington Crag also pushed inland in the period between 2 and 4. The Kelsey Hill deposits were probably carried inland at the same time as the Durham Kaims of Grindon, Warden Law, and Sheraton were formed.

² As already stated there is evidence for an advance of ice from Scotland along the coastal region of Northumberland before the western ice occupied the area.

⁴ On the hypothesis that there was an Interglacial period before the Scandinavian ice reached England; if only a Glaciation-Interval, then Preglacial as far as North-East England is concerned.

On *Eugyrinus wildi* (A. S. W.), a Branchiosaur from the Lancashire Coal-measures.

By D. M. S. WATSON, University College, London.

THE unique type-specimen of *Hylonomus wildi*, a small amphibian from the marine roof of the Mountain Four-feet Mine of the Lower Coal-measures at Trawden, near Colne, Lancashire, is now in the Manchester Museum, No. W 1222.

This specimen was accurately described by Dr. A. Smith Woodward (GEOL. MAG., 1891, pp. 211–13). Some time ago I decided to endeavour to develop the dorsal surface of the skull, and was successful in the attempt. The skull is quite uncrushed, although the quadratojugal of the left side had been separated before burial. It is now represented by an exquisitely sharp impression of the outer surface of the posterior half, squeezes from which display the structure with perfection. The mould of the inner surface of the whole head, except the extreme tip of the nose, is equally well preserved. The parasphenoid and right half of the palate are in place, but somewhat concealed by the lower jaw. Finally, a fracture passing along the quadrate ramus of the pterygoid makes the structures there visible.

The skull is very small, about 17 mm. in length and breadth, and 7 mm. in maximum depth.

The general form is triangular, the quadrate region being the widest part and the nose narrow. The dorsal contour is nearly straight, descending from the occiput to the shallow nose. In transverse section the outer surface is smoothly curved, the temporal bones continuing the surface of the "table".

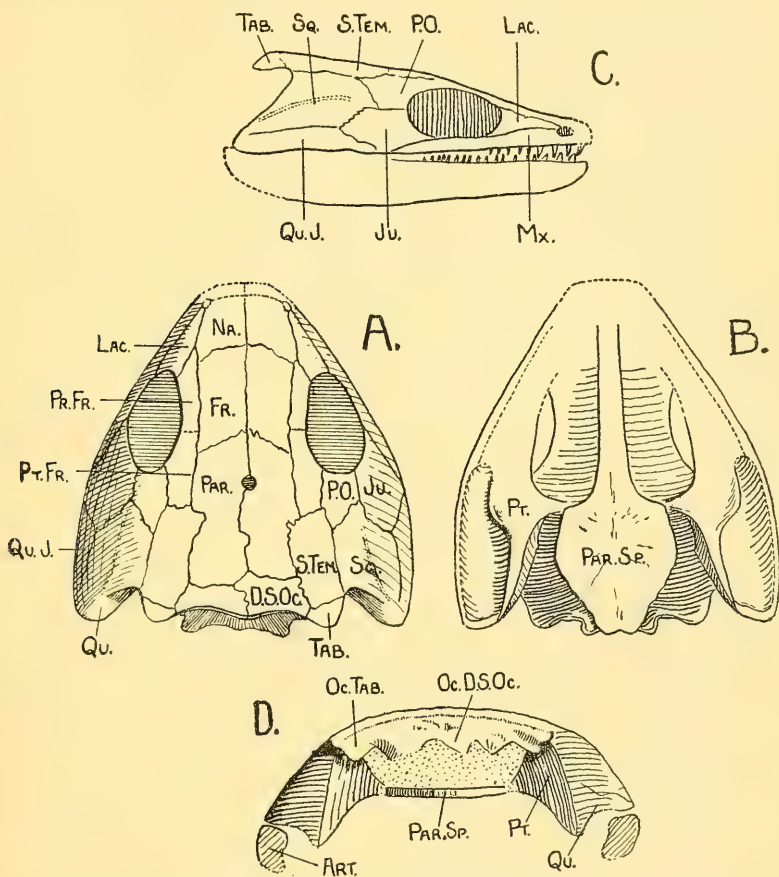
The orbits are large, lying in the anterior half of the skull and extending down to the upper edge of the shallow maxillæ. The interorbital surface is wide. The posterior edge of the right nostril is preserved and shows that these openings were small and widely separated. There is a small pineal foramen, just caudal of the hinder margin of the orbits.

The outer surface is covered by an ornament of small bosses, sometimes extended into ridges. There is a shallow groove for lateral line sense organs on the squamosal.

There are no ossifications in the neural cranium. The basis cranii is supported by a very large parasphenoid, which is posteriorly expanded into a thin hexagonal plate with a flat ventral surface. The processus cultriformis is wide, and extends very far forward.

The pterygoid is attached to the anterior corner of the enlarged plate of the parasphenoid by a narrow process, the exact details not being ascertainable. From this process the quadrate ramus passes backward as a high paraotic flange, whose upper edge touches the squamosal below the otic notch, whilst its lower margin is carried down below the general level of the palate to support the articular edge of the quadrate. The palatal ramus of the pterygoid runs

forward on the palate, and must articulate with the palatine and ectopterygoid, which bones are concealed by the lower jaw. There



Restoration of the skull of *Eugyrinus wildi* (A.S.W.) from the type (W 1222, Manchester Museum). Founded on camera lucida drawings of squeezes from the impression of the hinder part and of the mould of the anterior part. The left restored from the perfect right side. $\times 2.6$ approx.

A. Dorsal aspect.

D.S.Oc., dermo-supraoccipital; Fr., frontal; Ju., jugal; Lac., lachrymal; Na., nasal; P.O., postorbital; Par., parietal; Pr.Fr., prefrontal; Pt.Fr., postfrontal; Qu., quadrato; Qu.J., quadratojugal; S.Tem., supratemporal; Sq., squamosal; Tab., tabular.

B. Ventral aspect.

Par.Sp., parasphenoid; Pr., pterygoid.

C. Right lateral aspect. Reference letters as before.

D. Occipital aspect.

Art., articular; Oc.D.S.Oc., occipital flange of dermo-supraoccipital; Oc.Tab., occipital flange of tabular.

is a distinct flange from the pterygoid supporting the inner surface of the lower jaw as in *Eryops*.

The interpterygoid varieties are large, but the width of the palatine and pterygoid is considerable, the pterygoid in consequence passing far forward.

On the dorsal surface the hinder margin of the skull is formed by the small tabulars, which have rounded ends, and are not produced into horns, and by the considerably larger dermo-supraoccipitals. Both these pairs of bones have large descending flanges on the occipital surface, which, as in the later Labyrinthodonta, must have covered the paroccipitals and exoccipitals. The parietals are large bones, succeeded in order by the frontals and nasals. There is a large supratemporal, which articulates with the tabular, dermo-supraoccipital, and parietal on the admesian border, with the postfrontal and postorbital in front and with the squamosal laterally. Its border enters into the margin of the large otic notch. The squamosal lies on the side of the skull, articulating above with the supratemporal. Its caudal margin is turned in under the otic notch to be attached to the upper edge of the paraotic plate of the pterygoid. Ventrally of this union the bone covers part of the hinder surface of the well-ossified quadrate. There is a small quadratojugal. The series of circumorbital bones is complete, the lachrymal extending from the orbit to the nostril as in primitive reptiles. Owing to the large size of the orbit, the lachrymal and jugal do not meet. The structure of the lower jaw is undeterminable.

The vertebral column is largely concealed by the body squamation, but such parts of the neural arches as are visible agree exactly with those of *Branchiosaurus*, and present no resemblance to any Lepospondyl elements. The ribs of the pectoral region are as described by Smith Woodward, very stout, straight, and expanded at both ends; the later dorsal and caudal ribs, though more slender, are equally straight. Of the shoulder-girdle the interclavicle is as shown in the original description, a rounded plate of bone with a distinct radiating ornament. Fragmentary remains of clavicles of a scapula and perhaps of a cleithrum are shown; they agree with the corresponding elements of *Branchiosaurus*. In the pelvis the long, slender ilium and plate-like ischium are well shown from their visceral surface, but there is no trace of a pubis.

There is a complete covering of scales on both ventral and dorsal surfaces. On the belly these have a complex arrangement, not describable in detail but recalling that of *Branchiosaurus*.

The amphibian just described is clearly a Branchiosaur. Only in the Phyllospondyli amongst Palæozoic amphibia do comparable vertebrae, ribs, and squamation occur. It is the oldest known member of its order, *Eumicrerpeton*, *Mazonerpeton*, and *Micrerpeton*, described by Moodie from the Coal-measures of the United States, coming from the considerably higher horizon of Mazon Creek. The other European forms come from Stephanian and Artinskian rocks, and from different

horizons in the Rothliegende. Thus *Hylonomus wildi* cannot be referred to its original Microsaurian genus, and as it does not fall into any described Branchiosaur genus I propose for it the name *Eugyrinus*.

The skull of *Eugyrinus* is by far the best-preserved Branchiosaur skull known, and is much more primitive in its structure than that of the well-known Permian and Stephanian genera. It differs from *Branchiosaurus* in being much longer and narrower, and in having very much smaller orbits; it is, in fact, more like the central type of Labyrinthodont skull represented by *Eryops*.

In consequence of its smaller orbits, it retains a lachrymal, and has postfrontal, postorbital, jugal, and squamosal bones much more resembling the ordinary Labyrinthodont type than those of *Branchiosaurus*. The palate of *Eugyrinus* differs from that of *Branchiosaurus* in the narrower hinder part of the parasphenoid, which in it can by no stretch of the imagination be called T-shaped; and in the much smaller interpterygoid varieties and larger pterygoids which go with them. These differences are exactly those which separate such a Rachitomous amphibian as *Dvinasaurus* from its Stereospondylous descendant, *Plagiosaurus*, and go to show that the trend of evolution in Phyllospondyli is the same as that in Labyrinthodonta. *Eugyrinus* agrees in stage with an Upper Permian Labyrinthodont, *Branchiosaurus* with one from the Upper Trias.

The skull of *Eugyrinus* is very valuable, because it shows that the general structure of the early Phyllospondylian skull is identical in essentials with that of the Labyrinthodonta. In comparison with *Branchiosaurus* it shows that the Phyllospondyli had a similar evolutionary history to that of the Labyrinthodonta, carried through at a much earlier date, and of which only the latter half is known. As the latter parts of the stories of the two groups are similar we are surely justified in expecting that the beginnings will resemble one another, and that we may take the primitive Labyrinthodonts as representing structurally the unknown ancestors of the Branchiosauria.

Thus the known Phyllospondyli can in no sense be regarded as primitive amphibia; they represent the later members of a side-line which underwent a precocious and very rapid evolution.

Eugyrinus is of geological importance, because it adds another link to the chain of evidence which proves that North America and Britain formed a single zoological province in Upper Carboniferous times. The resemblance between the vertebrate fauna of the North American Coal-measures and that of Britain is very great. Several species of fish, a number of genera of fish and amphibia, and nearly all the definitely determinable families of vertebrates occur on both sides of the Atlantic. The flora is, of course, equally similar.

The resemblances are, in fact, so great as only to be explicable

by a continuous land-bridge crossing from Britain to Canada. The marine fauna living along the southern shore of this continent should be equally uniform; and as such a bridge must have had a representative in Lower Carboniferous times it should follow that the mountain limestone faunas of Britain should be in large part identical with those of the States. It appears probable that a comparison of their faunas, founded, not on literature, but on actual material, would be a most profitable undertaking, and that it might enable British geologists to make use of the evidence of a succession of faunas which has been collected by their North American colleagues.

On the Geological Features of the Oil Region in the Northern Punjab (British India).

By H. PREISWERK, Basle.

(Continued from p. 21.)

B. THE OIL REGION OF JABA IN THE WESTERN SALT RANGE, MIANWALI DISTRICT (see Figs. 9 and 10).

THE OIL-SPRINGS.

THE oil-springs of Jaba are situated at the foot of the steep limestone hills $1\frac{1}{2}$ or 2 miles distant from the village of Jaba and 7 miles from the railway station of Massan. On the topographical map (Sheet 38, p. 9, scale 1 inch = 1 mile) the two main oil-springs are marked. The north-western spring is called Chota Kutta by the natives, the south-eastern Burra Kutta, from the brooks where they are found.

The richest oil-spring is that of Chota Kutta. It is situated immediately at the entrance of a narrow ravine which has been cut by the little brook into the steep limestone ridge. The most important of the oil-shows are on the right bank of the brook. Oil issues at several places out of the Nummulitic limestone, together with water containing sulphuretted hydrogen. The total outflow of the natural oil-springs of Chota Kutta and Burra Kutta has been collected by the Chowkeedar during three months. The daily outflow was found to be about 1 gallon (4-5 litres), three-fourths of which issues at Chota Kutta according to Lyman's estimation.

In 1912 the production of oil of the Mianwali District was 950 gallons; 1916, 1,334 gallons; and 1917, 919 gallons.

In front of the entrance to the narrow ravine, at the foot of the limestone ridge and a few yards distant from the oil-springs, some shallow shafts have been dug, from which oil and gas issue. Also a little boring has been made—30 yards below the entrance to the ravine—the depth of which is said by the natives to be 300 feet.

I have taken a sample of the oil issuing from the boring. It is

a brown and rather mobile oil with a strong aromatic smell. The analysis of this oil gives the following results:—

Specific gravity of the crude oil : 0.9242
Flash-point 75° C.

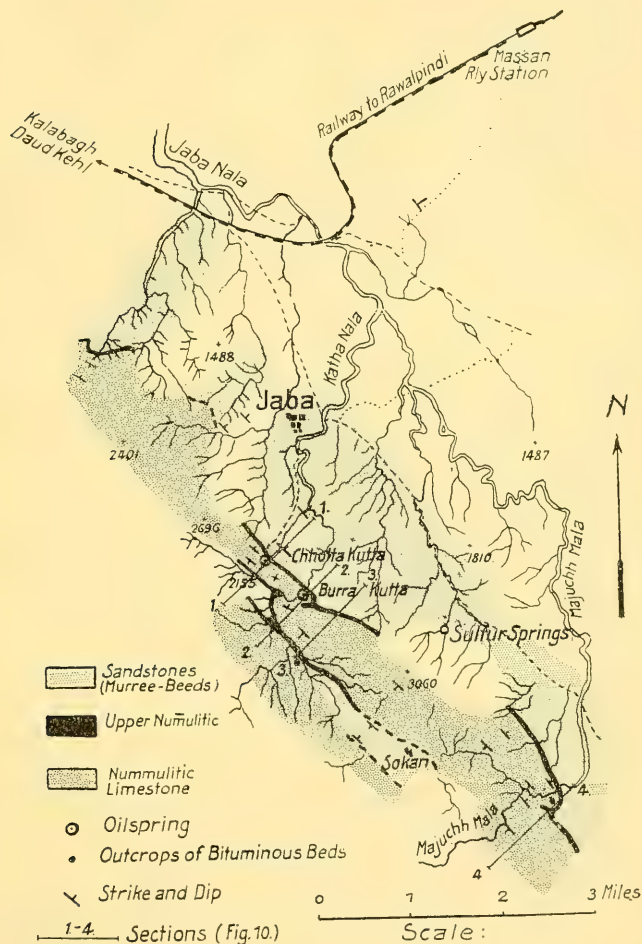


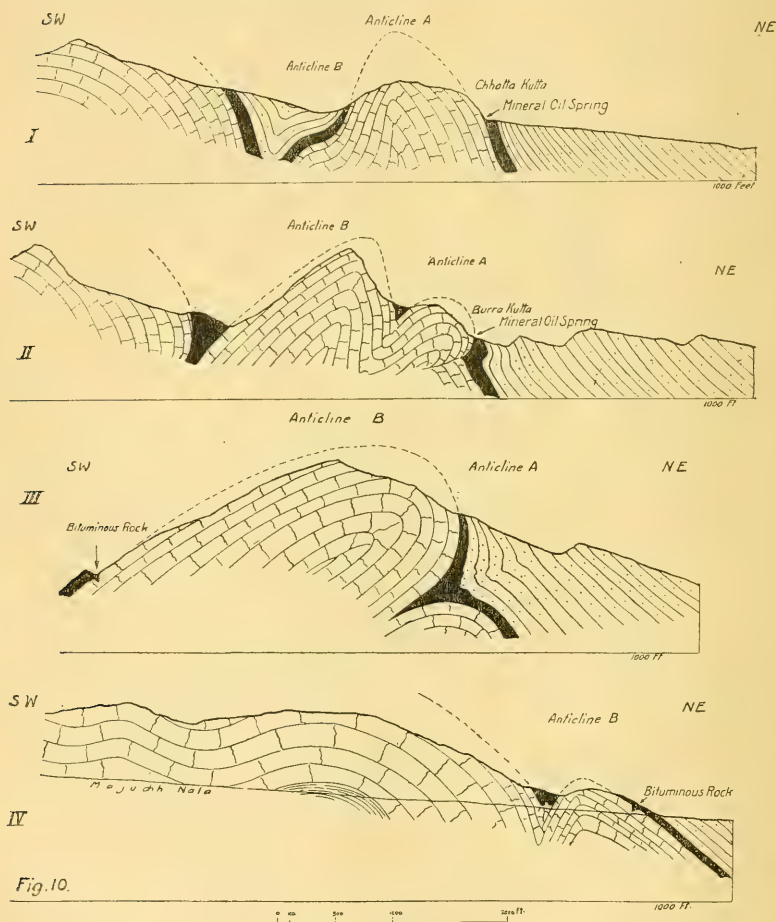
Fig. 9.

The fractional distillation gave by Engler's method:—

			Spec. grav.
I.	Fraction from 70° to 150°	0.6 per cent	—
II.	„ „ 150° to 250°	7 per cent	0.8460
III.	„ „ 250° to 300°	24.4 per cent	0.8736
IV.	„ „ over 300°	60.3 per cent	0.8905
	Residue.	7.7 per cent	—

The determination of paraffin in fraction IV gave a content of 30 per cent paraffin, while the remaining 70 per cent of fraction IV might be signified as solar oil. The whole amount of sulphur in the oil amounts to 0.43 per cent.

The oil, therefore, contains 31.4 per cent burning oil. The amount of paraffin, about 18 per cent of the crude oil, is very high. The sulphur content is moderate, and does not reach that of the limestone



oils of Ohio (0.5–0.6 per cent). The oil is to be called a heavy oil. Its composition is peculiar and hardly comparable with other oils.

The oil-spring of Burra Kutta is situated in a position quite similar from the topographical and geological point of view to that of Chota Kutta. There are about a dozen oil-shows, beginning at the

entrance of the steep ravine which has been cut through the limestone ridge by the Burra Kutta brook. The oil comes forth from the cracks of the Nummulitic limestone, mingled with sulphur water and sometimes with gas. The most westerly of the oil-shows I have seen in the Burra Kutta valley lies about 80 metres above the entrance to the gorge.

Geological Features.

Stratigraphy.—The oil-springs come forth from the uppermost beds of the Nummulitic limestone, which contains some marly layers. At the river-bank at Chota Kutta the beds lying over the limestone are covered by detrital deposits for a distance of 30–40 yards along the river. These beds, however, are very well exposed along the footpath leading through the gorge high above the brook on its north-western bank. They consist (1) of very porous limestones or dolomitic limestones (Zellenkalk, cargneule), accompanied by white gypsiferous clays. These beds are covered by (2) greenish gypsiferous clays and further by (3) pseudo-conglomeratic oolitic limestone forming a prominent ridge. This limestone consists of coarse ooliths containing in the core pieces of Nummulitic limestone. The same ridge of oolitic limestone is visible, too, down at the river bank, about 10 yards to the west of the footpath which leads from Chota Kutta to Burra Kutta.

In the sections (Fig. 10) I have marked these three characteristic rocks with the same signature of "Upper Nummulitic". Stratigraphically, as well as petrographically, there is a great concordance with the Upper Nummulitic beds in the environs of Rawalpindi. At the oil-springs of Gunda near Fatehjang, and further to the east near Kutbal, quite the same very characteristic porous limestone (cargneule) is found between the compact Nummulitic limestone and the gypsiferous marls of the Upper Nummulitic.

Above the oolitic limestones follow the Murree beds and the Siwalik group: a series of sandstones with red clays of enormous thickness.

The oldest rocks, represented in Section IV, Fig. 10, are lumpy marls lying below the Nummulitic limestone in the valley of the Majuchh Nala. These marls are rich in fossils, especially in well-preserved Echinoidea. I have collected, according to J. Baumberger's determination: *Cassidulus* cf. *ellipticus* and *Plesiolampas ovalis* (Ducan & Fladen, "Tertiary and Upper Cretaceous Fauna of Western India": Palæontologia Indica, 1883). The specimen *Plesiolampas* is embedded in clayey marls rich in *Assilina* and Nummulites.

These beds belong to the Eocene and perhaps correspond to the *Echinolampas* zone of Middlemiss.

The facies of the Upper Nummulitic in other parts of the Salt Range is of interest in regard to the extension of the oil-horizon. According to Lyman and to communications of natives tar occurs in the middle Salt Range in places which, according to Wynne's map,

must fall on the boundary between Nummulitic limestone and Murree sandstone.

In the eastern part of the Salt Range I had the opportunity in several places of studying specially the beds between the Nummulitic limestones below and the overlying sandstone formation. Near the hamlet of Mola, not far from Phadial, I observed the following section (Fig. 11).



Fig. 11.

The same beds are somewhat better developed in a brook north of the hamlet Lheri Saidan (Fig. 12) (*vide* topographical map, 1 inch = 1 mile, No. 43 H, District Jhelum). They probably represent the Upper Nummulitic. The strata dip to the north-west at about 20° . The nodular marls have exactly the same character as the corresponding bitumen-bearing beds of the region of Golra, Ratta Hotar, and Murree (Kuldana). They do not, however, bear bitumen here. In this as well as in the small thickness of the clayey formation between the Nummulitic limestone and the sandstones, the facies differs from that of the western Salt Range. Gypsum and cellular limestones are also absent.

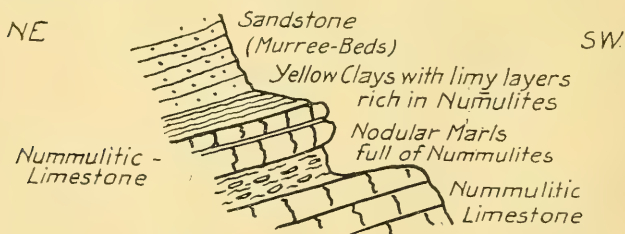


Fig. 12

Near Phadial, at the base of the sandstones, however, I have found the same giant oolite which, near Jaba in the western Salt Range, forms the rock overlying the oil-bearing beds. We find the giant oolites also in the middle Salt Range overlying the Nummulitic limestone. On the plateau south of Kallar Kahar (special map No. 43 D 9, Attock and Jhelum District) they are well exposed (*vide* Fig. 13). The giant oolite therefore marks a very

important stratigraphical horizon which almost throughout the whole Salt Range overlies the Nummulitic formation.

Tectonics.—The Sections I–IV on Fig. 10 show the most important tectonic features of the Jaba oilfields. From Massan towards the hills the inclination of the strata increases more and more. Near Massan the sandstones dip at about 10° only to the north-east, but their inclination increases to $50\text{--}60^\circ$ at the border of the Salt Range. At the oil locality Chota Kutta itself the limestone beds dip 60° . (Section I, Fig. 10.)

The inclination of the oolitic beds overlying the oil rocks is exceptionally steep (*circa* 80°). At about 700 feet to the south-west of the oil-springs the north-eastern dip ceases and a steep south-western inclination of the beds takes its place. To the west, behind the limestone ridge where the valley of Chota Kutta becomes flatter, the Upper Nummulitic beds appear again as well as the Murree sandstones. Thus the first range of the hills forms a normal anticline, the core of which is the Nummulitic limestone ridge. The Upper Nummulitic beds, as well as the oil rocks, have been removed by erosion above the anticlinal axis, and are only preserved on the steep flanks.

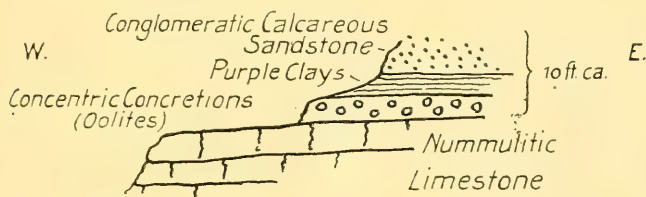


Fig. 13

Near the oil-spring Burra Kutta the first mountain range consists of two anticlines separated from one another by a shallow syncline (Section II, Fig. 10). The strata of the uppermost limestone beds from which the main oil-springs issue are nearly vertical or even overturned, dipping south-west. The overlying beds, however, are much less steep. Towards the hills the Nummulitic limestone beds form a well-curved arch. To the south-east, in the direction of the strike of the folds, the limestone dives below the Upper Nummulitic beds. This descending anticline is the direct continuation of the anticline A of the first section (Section I, Fig. 10). Both belong to the same fold, which may be recognized from the map (Fig. 9). But in Section II the crest of the anticlinal limestone core lies about 600 feet lower than in Section I—taking into account the masses removed by erosion. The axis of the anticline A (Sections I–III), therefore, dips at about 15° S.E. In Section II the main anticline is the anticline B. The axis of the anticline B

is inversely inclined to the north-west at rather a high angle, so that in Section I the anticline B has sunk completely underground. Its probable position in Section I is marked by a slight curve on the strata (on Fig. 10).

In Section III the dimensions of the two anticlines are still more different. The whole range is formed only by the anticline B, the anticline A having sunk completely underground.

Farther to the south-east the high ridge culminating at the point 3,060 feet (Fig. 9), is entirely formed by the limestone core of the anticline B.

In these—from the geological point of view—young folds of the western Salt Range the shape of the surface is in strict mutual relation with the geological structure of the ground. Thus, for instance, it can easily be observed from a distance of several miles that the axis of the anticline B inclines south-east towards the valley of the Majuchh Nala. I have therefore examined the outcrops of this valley, and indeed I found that the crest of the anticlinal limestone core rises only very little above the Majuchh Nala, and a few hundred metres farther to the south-east of the river the whole limestone arch is entirely covered by the Upper Nummulitic deposits. The pitch of the descending anticlinal axis is about 15° . (Figs. 9 and 10, Section IV.)

Higher up the Majuchh valley the Nummulitic limestone forms some flat folds and rises up over the older formations lying below. The Upper Nummulitic and the Murree beds are limited to the north-eastern exterior border of the hills.

From the description given above it follows that the predominating structure of the north-eastern border of the western Salt Range is a typical example of folding. There are several folds alternating in such a way that the folds lying more inside of the hills approach—striking south-east—the exterior border, while the folds of the border disappear from the surface descending below the ground level. The different anticlines appear distinctly as mountain ranges, and disappear from the surface owing to the pitching of the anticlinal axis.

(*To be concluded.*)

REVIEWS.

GEOLOGY OF INDIA FOR STUDENTS. By D. N. WADIA, M.A., B.Sc.
pp.xx + 398, with 20 plates and 37 figures in the text. London:
Macmillan & Co. 1919. Price 18s. net.

THE last edition of the *Manual of the Geology of India* appeared in 1893. Since that date Vredenburg's *Summary of the Geology of India* (1907) and Holland's article in the *Imperial Gazetteer of India* (1907) have been published; but both of these are brief, and Mr. Wadia, accordingly, deserves the gratitude of geologists at home as well as in India for giving us a volume on a scale commensurate with the importance of the subject. Unlike the *Manual* his book is not official; it is written as a textbook for University students, and, perhaps for this reason, it is easier to read and follow than most official publications. It is, indeed, so clear in style and arrangement that it may even arouse the attention of geologists who have been deterred by the difficulties of an unfamiliar nomenclature from studying the great problems of Indian geology.

Several of these are of universal interest. Few parts of the world offer conditions more favourable for the study of the "Fundamental Complex" than the Indian Peninsula, and though the Geological Surveys—of the native states as well as of the Indian Government—are compelled to devote their attention primarily to questions of economic importance, considerable progress has been made in recent years in the elucidation of its more important features. We now know that a large part of the Complex consists of intrusive masses, which in some cases are of later date than the beds which rest upon it.

But it is to the mountain ranges of the north that geologists in general look with the greatest interest. The contrast between Peninsular and extra-Peninsular India, both in structure and in the character of the deposits, was pointed out even in the first edition of the *Manual*, and later observations have only emphasized the difference. The researches of Middlemiss and others on the tectonics of the Himalayas and the other bordering ranges are of the greatest importance with regard to the general problem of mountain-building; and the question of isostatic compensation is of interest not only to the geologist but also to the geodesist.

Though a full discussion of such questions would be impossible and out of place in a textbook, Mr. Wadia gives an excellent summary of the present state of our knowledge of Indian geology, with references which will serve to guide the inquirer through the Memoirs and Records of the Geological Survey. Being himself a lecturer at the Prince of Wales' College at Jammu, in Kashmir, he has added a special appendix on the geology of that province, which, as he says, "contains one of the finest developments of the stratified record seen in the Indian region."

The book is admirably produced, and the use of heavy type for the headings of sections and the addition of sub-headings in the margin make it very easy to refer to. Illustrations are not numerous, but in addition to text-figures there are a dozen plates reproduced from photographs and a number of black and white maps of different regions. There is no general geological map, which would have necessitated the use of colour and would have greatly increased the cost of production; but since the map issued by the Geological Survey is available, it was certainly wise not to increase the expense of the book unnecessarily, and considering the circumstances the price has been kept remarkably low.

P. L.

TYPE AMMONITES. By S. S. BUCKMAN. Part XIX, August, 1919; XX, October, 1919; XXI, March, 1920; XXII, June, 1920. pp. 5-18, with 53 plates and a portrait. Published by the Author. Sold by W. Wesley & Son.

PART XIX begins vol. iii of this work, of which the title of the previous volumes is *Yorkshire Type Ammonites*. No indications are given as to whether the author contemplates limiting the scope of the work to the Jurassic Ammonites of the British Isles or giving it a more extensive stratigraphical and geographical range. Additional terminology is proposed, and the following generic names introduced: *Lamberticeras*, *Vertebriceras*, *Korythoceras*, *Pavloviceras*. The first of these names was found to be pre-occupied, and is replaced by *Bourkelamberticeras*. *Prionodoceras* is introduced in place of *Prionoceras*. In a section on "Development" the author says, "The early Orthocones utilising the gas effusion, which resulted from temporary indigestion under the nervous apprehension of danger, found that a cone thus made more buoyant was a help in rapid retreat from foes."

THE MINERAL INDUSTRY OF THE BRITISH EMPIRE AND FOREIGN COUNTRIES. Imperial Mineral Resources Bureau Digests. Chrome Ore and Chromium, 29 pp., 1s. net; Magnesite, 42 pp., 1s. 3d. net; Monazite, 15 pp., 6d. net; Felspar, 16 pp., 6d. net; Borates, 24 pp., 9d. net; Fuller's Earth, 15 pp., 6d. net; Nitrates, 28 pp., 9d. net; Arsenic, 19 pp., 6d. net; Bismuth, 14 pp., 6d. net; Asbestos, 34 pp., 1s. net. Stationery Office, 1920.

THE ten pamphlets listed above are the advance guard of what is intended to be eventually an annual volume somewhat on the lines of that well-known American publication *The Mineral Industry*, containing information on the mineral resources of the world, with special reference to the British Empire and its needs. The present publications are to a great extent a review of the progress or otherwise of each industry during the War period, 1914-1919.

They do not profess to be complete monographs, but rather synopses of the information available for the period under review. The information given is largely statistical, but useful sections are included indicating the mode of occurrence and principal industrial applications of each mineral, together with in each case a bibliography of recent technical publications bearing on the subject: this is an excellent feature. The particulars given appear to be very accurate and up-to-date, and these small handbooks will be of great value to all concerned in the various industries. We shall anticipate the appearance of the complete volume with much interest. It is stated in the prefaces that in future great use will be made of graphic representation of statistics. We are inclined to regret this, as in our opinion such graphs have been overdone of late years. They take up a lot of room, and may be misleading unless all are on the same scale and refer to the same units, which is usually impossible.

LORRAINE AND SAAR MINEFIELDS. Handbooks of the Historical Section, Foreign Office, No. 31. 30 pp. 1920. Price 1s. net.

THIS small pamphlet, one of a series prepared by the Foreign Office for the information of delegates to the Peace Conference, contains an excellent summary of the geography, geology, production, and reserves of the iron-mining district of Lorraine and Luxemburg and of the coalfield of the Sarre. The enormous importance of the minette of Lorraine as a factor in the iron and steel trade of Europe is well brought out, and the political aspect of the matter is clearly explained, as it stood before the terms of peace were settled. The somewhat inferior character of the Sarre coals, and their unsuitability for metallurgical coke, are rightly insisted on, and the difficulty of obtaining an adequate supply of coal and coke for France is discussed; it is suggested that the best solution is to be found in an extension of the canal system and improvement of existing waterways.

A TEXTBOOK OF GEOLOGY. By PHILIP LAKE, M.A., F.G.S., and R. H. RASTALL, M.A., F.G.S. pp. xiv and 508. Third edition. 1920.

A COPY of the above textbook is recognized as part of the present-day equipment of every geological student, and its value and popularity are both proved by the welcome appearance of a revised third edition, that treads closely upon the heels of a second impression of the previous issue, reviewed in the February number of the *GEOLOGICAL MAGAZINE* for 1911.

Whilst retaining in the main the well-arranged form and contents of the earlier editions, the present book has been thoroughly revised and enlarged. The section on coral reefs has been enriched by notes on the results of investigations of American geologists such

as Dana, Davis, and Daly, whose work affords strong support to Darwin's theory of submergence.

A chapter on ore deposits has been rewritten by Mr. Rastall. The study of ores is a branch of petrology, and a scientific classification of ore deposits must be based ultimately upon their mode of origin. We may recognize primary ores, vein deposits, cavity fillings, replacement deposits, and sedimentary ore deposits besides those formed by metamorphic action.

An interesting section on the history of igneous activity in the British Isles is also contributed by the above-named writer as a supplement to Mr. Lake's précis of the geological history of the British Isles. Earth movements and igneous activity are so closely interrelated that it is impossible to consider them apart. In an area like North Wales, for example, where post-Carboniferous movements are pronounced, it is important to realize that although no igneous rocks ascribed to that period are visible, such rocks may nevertheless underlie a large part of the district. A map of the chief folds and faults of Northern England and Wales is given in plate xxiv.

The classification of the Permo-Trias of Cumberland and the Vale of Eden does not appear to be satisfactory. In the first place gypsaceous shales and marls apparently occur in the top of the so-called Permian of the Vale of Eden, as well as in the bottom of the Trias. Again, no mention is made of the Keuper Kirklington Sandstone, which is asserted by Professor J. W. Gregory to overlie directly the St. Bees Sandstone, not only of Northern and Western Cumberland, but also of the Isle of Man. These are minor details, however; a wider question is involved in the consideration whether any clear-cut division can be established between the so-called Permian and Trias in Western Cumberland.

As regards the general direction of travel of glacial erratics, it may be mentioned that a boulder of Shap Granite was found by the writer at Bledworth in Nottinghamshire, far south of the limits shown in the map, fig. 34.

The book is well illustrated, printed in clear, readable type, and furnished with a useful index.

B. S.

THE DATA OF GEOCHEMISTRY. By F. W. CLARKE. Fourth edition. Bulletin 695, U.S. Geol. Survey. 832 pp. 1920.

WE are glad to welcome the appearance of the fourth edition of this invaluable work, which exceeds its predecessor in size by about ten pages. In the absence of any prefatory remarks it is difficult to obtain any idea of the extent of the changes in a book of this size and nature, but a casual examination and an inspection of the footnotes and index show that a large amount of the most recent work has been noticed. This book has always been remarkable not only for the skill with which a vast amount of information has been compressed into a comparatively small space, but also for the

reasonable and common-sense attitude adopted in controversial questions. Many current subjects are discussed in an impartial manner, the arguments on both sides being fairly stated. As an example we may perhaps quote the temperate summary given on pp. 416-29 of the difficult problem of the classification of the igneous rocks, a subject which has of late attracted much attention on both sides of the Atlantic, and is admittedly as yet far from settled. The petrologist, mineralogist, and economic geologist will find in this book a mine of information on many little-known points of interest, together with voluminous references to original memoirs. By a rough computation the index contains nearly 7,000 headings, and there are few workers in any branch of geology who will not here find some new and valuable information often culled from the most recondite sources.

SPECIAL REPORTS ON THE MINERAL RESOURCES OF GREAT BRITAIN
Vol. VII: Mineral Oil, Kimmeridge Oil-shale, Lignites, Jets,
Cannel Coals, Natural Gas, England and Wales. Second
edition. pp. iv + 125, with a plate and 7 text-figures. 1920
Price 5s. net.

THE second edition of this interesting and useful memoir has been enlarged and amplified by an account of the explorations lately going on for oil in Great Britain, brought up to the date of going to press. We note, however, with regret that this date is as far back as June, 1919. A map is given showing the position of the borings in the Chesterfield-Mansfield district, and their relation to the geological structure, together with a general section of the Carboniferous strata of Derbyshire, and a diagram showing the lie of the rocks along a line from Ashover past the Hardstoft boring. From this it is clear that the small accumulation of oil there was due to a roll in the strata combined with specially favourable local conditions. The total production up to October, 1919, was 849 barrels—a quantity which is of no practical significance as a commercial proposition, taking into account the cost of a 3,000 feet bore.

A short account is also given of the work undertaken for the establishment of a Kimmeridge oil-shale industry in Norfolk, with a description of the strata encountered in various borings and shafts. Fossils have been recognized belonging to both Lower and Upper Kimmeridgian zones, and some horizons are richly fossiliferous.

An investigation of the cannel and other oil-yielding rocks has shown that cannels are of strictly local development, and the best seams are nearly exhausted. This does not seem to show any promise of being a future source of commercial oil-supply.

R. H. R.

SPECIAL REPORTS ON THE MINERAL RESOURCES OF GREAT BRITAIN.
Vol. XIII: IRON ORES (CONTD.), PRE-CARBONIFEROUS AND
CARBONIFEROUS BEDDED ORES OF ENGLAND AND WALES. By
Sir A. STRAHAN, W. GIBSON, T. C. CANTRILL, R. L. SHERLOCK,
and H. DEWEY. Mem. Geol. Survey. pp. iv + 123, with
plates and 10 figures. 1920. Price 7s. 6d. net.

IT has long been a cherished conviction with writers of school geographies and similar books that the iron-mining industry of the British Isles is located in the coalfields. A careful study of this publication may perhaps help to disabuse them of that entirely out-of-date idea. It is here brought out clearly that the production of iron-ore from the Coal-measures is now of trifling importance, and though much smelting is still done in the coalfields, this is solely because of the presence of coal and not of iron-ore. As a matter of fact the output of Coal-measure ironstones is now about 8 per cent of the British total, and is declining yearly.

An interesting account is given of the deposits of iron-ore still worked spasmodically among the Lower Palæozoic rocks of North Wales; most of these are oolitic, often incorrectly called pisolitic, and far too rich in sulphur, since they appear to be formed largely by oxidation of pyrites or marcasite.

The blackband and clayband ironstones are still worked to some extent in North Staffordshire, and near Bradford, where the famous Low Moor iron is produced. In the other coalfields the industry is nearly extinct, though large reserves undoubtedly exist, especially in South Wales, where they are conservatively estimated at 5,000,000,000 tons. A great change in industrial conditions must occur before these become economically possible sources of iron on a large scale.

THE ECONOMIC GEOLOGY OF THE CENTRAL COALFIELD OF SCOTLAND,
AREA IV: PAISLEY, BARRHEAD, RENFREW, AND THE WESTERN
SUBURBS OF GLASGOW. By L. W. HINXMAN, E. M. ANDERSON,
and R. G. CARRUTHERS. Mem. Geol. Survey, Scotland. pp. iv +
110, with viii plates and 5 text-figures. 1920. Price 6s. net.

THIS volume contains a detailed account of the economic geology of the western part of the Central Coalfield; the area dealt with includes, south of the Clyde, the districts of Thornliebank, Hurler, Barrhead, Paisley, Johnstone, Renfrew, and Ibrox, while north of the river it extends from the suburbs of Glasgow to Duntocher, Milngavie, and the Kelvin valley above Balmore. The method of treatment is similar to that adopted in the four volumes of the series that have already appeared. The Coal-measures in the strict sense cover very little ground in this area, but the coal and ironstones of the Carboniferous Limestone Series have been extensively worked in the past and are by no means exhausted, especially south of the Clyde.

The volume also contains somewhat detailed accounts of two special features of much interest, the Paisley Ruck and the Thick Coal of Quarrelton. The Paisley Ruck, although a leading tectonic feature, appears not to have been hitherto described. It is essentially a crush-zone or shatter-belt, of generally anticlinal form, beginning on the north side of the Clyde near Drumchapel, and extending south-westwards, past Paisley and Johnstone, and through the Lochwinnoch gap into Ayrshire. Within this zone, which is from 150 to 200 yards broad, the strata are extraordinarily broken and contorted, while the edges are as a rule sharply defined by faults with varying displacement. Near Linwood the throw of the fault on the northern side is at least 1,800 feet, though usually much less.

The Thick Coal of Quarrelton appears to be formed by the local coalescence of several seams, and has a normal thickness of nearly 50 feet. But there are also at least two cases of local "doubling"; in one of these the enormous thickness of 100 feet of coal, or coal with thin clay partings, is attained. It is shown that the thick seam was originally laid down against a steep slope of the underlying lavas, and that the duplication was caused, not by overthrusting but by a contemporaneous process analogous to a bog-slide. This fact seems to have some bearing on current discussions as to the origin of "wash-outs" in other coalfields.

R. H. R.

DIE SULFID-SILIKATSCHEMELZLÖSUNGEN, I: DIE SULFID-SCHEMELZEN UND DIE SULFID-SILIKATSCHEMELZEN. By J. H. L. VOGT. Vidensk. Selsk. Skrifter, I Mat.-nat. Klasse, 1918, No. 1. 132 pp., with 45 text-figures. Kristiania, 1919.

DIE SULFID-SILIKATSCHEMELZLÖSUNGEN. By J. H. L. VOGT. Norsk. Geol. Tidsskr., vol. iv. 97 pp., with 13 text-figures. Kristiania, 1917.

THESE two publications contain the results of researches undertaken by Professor Vogt during the last few years on the physical chemistry and mineralogy of the sulphides and their relations to silicate melts, with special reference to the slags obtained in the smelting of copper matte. The first-named and larger work forms a third part of Professor Vogt's well-known work *Die Silikatschmelzlösungen*; the second contains a summary of the results set forth in the larger volume, published at an earlier date owing to difficulties encountered on the production of the complete work under war conditions. We are also informed in a preface that another memoir is in preparation dealing specially with the nickeliferous pyrrhotite ore-bodies, which are here only referred to incidentally. The publication of this will be anticipated with much interest by all mining geologists. Professor Vogt also states that he has in hand a nearly completed work on crystallization and magmatic differentiation in the basic intrusive rocks.

The facts here set forth are of the greatest possible interest, both in their technical applications to furnace practice and in their bearing on theoretical petrology and the genesis of the sulphide ores. It is now generally accepted that silicate melts of whatever composition are completely miscible in all proportions, but with regard to the relations between fused silicates and sulphides the conditions are quite otherwise. Silicate and sulphide melts, as well as silicates and molten metals, possess only very limited mutual solubilities, and in the fused state must form systems of two liquid phases. This proposition is, in fact, self-evident, since it forms the foundation of all smelting processes. Pig-iron and slag separate in the blast-furnace, not because the molten iron is heavier than the slag, but because the two liquids are mutually insoluble at the furnace temperature, and the same applies to the separation of sulphide and slag in copper matte smelting. In both these processes it is obviously desirable to have the cleanest possible separation of metal or sulphide and slag, and it is the investigation of the conditions most favourable to this clean separation that is the chief object of Professor Vogt's researches.

In the first place, it is evidently desirable that the slag should be as liquid as possible, partly in order that it can be drawn off easily and partly to facilitate the sinking of globules of sulphide, which might otherwise remain entangled in a viscous slag. This can be obtained partly by employment of a very high furnace temperature, which is undesirable from the point of view of fuel consumption and running costs. It is found, however, that the viscosity of the slag is very clearly a function of its chemical composition, and especially of its silica percentage. This also has a very important bearing on the solubility of sulphide in slag; this solubility varies inversely as the silica percentage, and directly as the temperature. Very basic slags at a high temperature cause the greatest losses of copper in matte-smelting, and this loss is apparently increased by the presence of much zinc. The practical problem is therefore to find the best working conditions, so that the two opposed factors may compensate each other. The loss of copper inevitable with a liquid basic slag in which the solubility is high has to be balanced against the loss of copper in a viscous acid slag with low solubility, but with a strong tendency to mechanical retention of sulphide. This is a nice example of the application of mineralogy and petrology to problems of the highest practical importance, a point of view which appears to be scarcely appreciated by British petrologists.

Rather more than half of the smaller work here reviewed is devoted to a discussion of the nickeliferous sulphide segregations and their relation to the norites. This is presumably a summary of the forthcoming larger publication before mentioned. It is shown that nickeliferous sulphides have a strong tendency to occur along with rocks rich in rhombic pyroxenes, which are mainly magnesia-iron

silicates, rather than with the more calcareous diopside-rocks or normal gabbros. A few sulphide masses of this type are found along with olivine rocks, especially peridotites. The physical chemistry and equilibria of the norite magmas are discussed, and it is shown that many of them approximate closely to eutectic composition (anchieutectic rocks). Most of the great pyrrhotite deposits are associated with norites that contain more hypersthene than corresponds to the eutectic limit between labradorite and hypersthene; where feldspar is in excess sulphide segregations are much less common. In the cases described it is quite clear that the pyrrhotite crystallized later than the pyroxenes, olivine, and feldspars. Incidentally it is of interest that, however quickly cooled, sulphides are always completely crystalline; no such thing as sulphide glass is known to exist. This behaviour is in strong contrast to that of the silicates. Likewise, it appears that owing to the highly mobile nature of fused sulphides, under-cooling does not occur to any appreciable extent, but sulphides crystallize sharply close to their true freezing-point.

All the phenomena attending the occurrence and crystallization of the sulphide segregations and their consanguineous silicate rocks become easily intelligible when it is once fully realized that silicates and sulphides possess very limited mutual solubility, and at the normal temperature of intrusion must of necessity form two liquid phases; this conception greatly helps in the solution of the problem of the genesis of the great nickel deposits of Sudbury and others, a problem which has of late years led to so much discussion by many petrologists, both from its inherent interest and from its great technical importance.

R. H. R.

REPORTS AND PROCEEDINGS.

ROYAL GEOLOGICAL SOCIETY OF CORNWALL.

November 14, 1920.

“On the Geology of St. Michael’s Mount.” By E. H. Davison, B.Sc., F.G.S.

The granite of the island is not of normal character, but shows idiomorphic crystals of quartz and felspar in a fine-grained crystalline ground-mass. The predominant type of alteration is greisenizing, the granite being traversed by a series of narrow parallel veins of greisen, with a central portion of pegmatite or of quartz, which carries such minerals as cassiterite, blende, wolfram, chalcopyrite, molybdenite, apatite, lithia mica, fluor, tourmaline, beryl, etc. The slate in contact with the granite shows evidence of intense thermal metamorphism, and in some cases there is evidence of the granite having absorbed the slate along the contact. Impregnation of the slate by minute granitic veins is also common. The lodes are seen in the form of greisen veins carrying mineral and in the form of more typical fissure lodes, and they occur in great numbers in both granite and clay-slate, but are all narrow. A clean ferruginous sand occurs in the island, which in many respects resembles St. Erth Sand. Tourmalinization is the exception, and the author concludes that the veins were filled by magmatic solutions which were highly siliceous and contained fluorine to a considerable extent, but little boron.

“Note on an Alluvial Pebble from Nanpuska.” By E. H. Davison, B.Sc., F.G.S.

The special interest of the pebble lies in the relationship of the quartz and cassiterite. The pebble is triangular, the apex being formed of a small mass of dark-brown zonal cassiterite, with quartz above, through which needles of cassiterite are arranged radially. The microscope shows the quartz to be a mosaic, and the quartz and cassiterite needles must either have crystallized simultaneously or the needles crystallized in a solution of silica sufficiently viscous to hold them in position.

“Note on an occurrence of Granite at Bridge.” By E. H. Davison, B.Sc., F.G.S.

In a quarry at Bridge, $1\frac{3}{4}$ miles north of the margin of the Carn Menezes granite, a quartz porphyry dyke was seen to contain a large xenolith of granite just above the foot wall. The granite showed no signs of having been melted along its margin, and seems to have been carried but a short distance. This confirms the view that the slope of the Carn Menezes granite mass to the north is very gentle.

“The Geology of Killifreth Mine.” By H. Kitto.

A detailed description of the geology of the mine and the lode characters. The country rock is mostly slate, but a quartz porphyry dyke is cut in two levels, and a tongue of granite is met with about 40 fathoms from surface and a tongue of schorl rock nearer surface. The minerals of the lodes include cassiterite, wolfram, mispickel, pyrite, blende, molybdenite, and smaltite. Several of the lodes show filling in two distinct stages, and the values are high but patchy. The author discusses an interesting case of a lateral fault without vertical displacement.

“The Geology of Carn Marth.” By G. MacPherson.

The geology of the district round Carn Marth is described with special reference to the igneous rocks. The so-called differentiated granite of the top of Carn Marth is considered by the author to be three successive intrusions of different types of granite; first the coarse-grained type, second the fine-grained granite without tourmalinization, third the tourmalinized fine-grained granite. Pegmatite and aplite veins also occur in the granite.

YORKSHIRE NATURALISTS' UNION.

December 4, 1920.—At Bradford.

Presidential Address by Professor J. E. Marr, Sc.D., F.R.S.

Professor Marr dealt with the tract of country comprising north-west Yorkshire and parts of the country lying to the north, where Carboniferous rocks are nearly horizontal over a wide area. He maintained that this tract had formed a rigid block of earth's crust, certainly since the beginning of Carboniferous times, and possibly for a longer period. Referring to Mr. R. H. Rastall's work on the Ingletonian rocks, which contain fragments of crystalline schists, he argued that a core of ancient rocks lay under the Carboniferous strata, and that newer rocks had been folded against this core at various times on the south, west, and north. The rigid block is bounded on the west and south by the Pennine, Dent, and Craven faults, and he gave reason for supposing that as movement went on against the block at different times, parts of the compressed rocks were added to the rigid block, causing it to grow outwards, the newer fault-lines lying further away from the centre of the block than the older ones. He supported this by special reference to the tract of Edenside, west of the Crossfell portion of the Pennine Chain, where there appeared to be evidence of faulting at the end of Carboniferous times, subsequently in Permo-Triassic times, and later still possibly in the Tertiary era. Similar changes seemed to have occurred to the south, along the Craven system of fractures. There was, however, some difference in the nature of the earth-waves affecting the areas to the west and south of the rigid mass. The former were comparable with the great rollers of the ocean, those of the latter rather

with the conflicting waves of a choppy sea. Were, he asked, the smallest of these of the nature of eddies swirling on the larger waves? There was a reference to the origin of Mr. Tiddeman's "reef-knolls", the mystery of which would, he hoped, be cleared up by Yorkshire geologists.

The address concluded by referring to various matters geological and physiographical, and concluded with the geographical distribution of organisms which were more or less dependent upon the character of the rigid block.

EDINBURGH GEOLOGICAL SOCIETY.

Mr. E. B. Bailey, M.C., B.A., F.G.S., F.R.S.E., President, in the chair.

1. "A new Volcanic Vent and other new Geological Features on the Shore, Weak Law, Gullane." By T. Cuthbert Day, F.C.S., F.R.S.E.

The place referred to is a wild, rocky stretch of coast, about half a mile in extent, a little to the west of the Island and lighthouse of Fidra. The author demonstrated by means of a map and lantern views the geological structure of the shore. Summing up the work commenced in 1914 and continued in 1919 and 1920, he sought to establish the presence on the shore at Weak Law of the following features:—(1) A considerable fault running along the shore from S.W. to N.E. with a downthrow to the N.W. of 200 feet or more. This fault brings down the Carboniferous shales of a considerably higher horizon to the level of the lowest bed on the shore, which is a nearly horizontal flow of a very vesicular trachyte lava. This lava is itself visibly overlaid by trachyte tuff and trachyte lavas to the height of 50 feet at least in the cliffs. (2) A great mass of intrusive igneous material, the matrix of which appears to be composed of white trap; the whole intrusion is highly charged with fragments and blocks, particularly of shale and ironstone. This intrusive mass fills the line of fault, cementing itself to both sides, and sending extensive tongues into the trachytes of the shore. (3) A sill of white trap in the shales, near low-water mark, and connected with the main intrusion. (4) A small intrusive boss of trachyte piercing the trachyte lava of the shore. It is of different material to that of the lava, being very compact and showing many decomposed phenocrysts of sanidine and a great number of scattered granules of augite. (5) A volcanic vent, about 230 yards in diameter, breaking through the older trachyte rocks of the shore, and itself subsequently truncated by the fault before-mentioned, and invaded by the intrusion filling that fault. The presence of this vent was shown by the following evidence: A boundary-line can very readily be traced; the lavas and tuffs outside the boundary dip inwards towards the vent. The ash within the vent is everywhere essentially different to that found outside, a characteristic feature being that it is highly charged with dolomite

and ferrous carbonate. Buried within the ash filling the vent are great masses of a rock composed of a sandy, dolomitic clay, of a nature not occurring on the shore in the immediate neighbourhood, and evidently belonging to a higher horizon. It is manifest also that the cliffs themselves have been breached by the vent, and a large, nearly semicircular recess has thus been produced. In the ash of the vent numerous blocks and bombs of trachyte were found. (6) The remains of a bed of very coarse conglomerate which lies unconformably across the outcrop of shales at low-water mark. This bed is apparently of very modern origin, and points to a time when the land was somewhat higher, and probably covered with sand dunes having many pebbles and rocky fragments at their base. These have been cemented in a sandy matrix, all bound together by carbonate of lime derived from the water which has filtered down through the sand dunes. (7) A peculiar structure in the rocks on the shore; it is of some size, and is bounded by a semicircular fault with a hade inwards of 30 to 45 degrees. It resembles a ring fracture of the strata caused by the sudden subsidence of a limited area.

2. "An Exhibit of Maps and Memoirs of Anglesea, by Edward Greenly, F.G.S." By the President.

GEOLOGISTS' ASSOCIATION.

Friday, January 7, 1921.

"The Post-Pliocene Non-marine Mollusca of the East of England." By A. S. Kennard, F.G.S.; and B. B. Woodward, F.L.S., F.G.S.

This paper deals with the non-marine mollusca of the Pleistocene and Holocene deposits of the counties of Suffolk, Cambridge, Northampton, Huntingdon, Hertford, Bedford, and Norfolk (except the Forest Bed).

Sixty-five localities are dealt with, thirteen being new, whilst a large amount of fresh material has enabled the authors to make many additions and corrections to the previously published lists. Notes on some of the more important species are given.

The authors are of opinion that the evidence furnished by these deposits fully supports their previously expressed views as to the sequence of events in the Pleistocene period, viz. that there has been one glacial period only, and that it occurred at the end of the Pleistocene.

CORRESPONDENCE.

GEOLOGY OF THE NINGI HILLS.

SIR,—I hasten to express my regret that I did not mention the fact that in 1911 Dr. Falconer mapped the Ningi-Kila-Fagam granites. I am afraid that I am so familiar with and indebted to "The Geology and Geography of Northern Nigeria" that I forgot that others might not be equally acquainted with it.

I do not understand what is meant by "local controversies". So far as I know Dr. Falconer is the only geologist who has written anything on the geology of this area, and also I do not see how these preliminary notes, based on a prospector's notebook, can be regarded as controversial. It would have been better, I admit, to have retained Dr. Falconer's non-committal nomenclature of the "younger granites", at any rate pending further research.

It is, however, difficult to follow the rest of the letter. In the map that accompanies Dr. Falconer's book the area covered by my traverse is, with the exception of the Ningi, Kila, and Fagam Hills, entirely mapped as ancient crystalline rock, as part of the great mass of archæan rocks that form the basal plain of Northern Nigeria. I have not the book by me at present, as I am on trek, but I am almost certain that, as shown on the map, Dr. Falconer's itinerary passed up from Sabon Garri, through Tipchi, and thence to the Ningi Hills. It passes therefore over the area I mapped as Sabon Garri granites, and along the same rocks in the shadow of the great mass of Duchin Chanya Cherigi.

It was on this authority that I classed these granites as archæan, for in all respects they correspond with the archæan granites described in the book, notably in that they show ill-defined margins with the gneisses and never, like the "younger granites", show any contact alterations. If, then, my Sabon Garri granites are merely "a number of outcrops of younger riebeckite granite projecting through older micaceous gneisses of various types", they should, according to Dr. Falconer, be accompanied by well-defined contact alterations. But there is no sign of such alteration, and though Nos. 100 and 105 were taken close to the edge of the mass and near to the schists and gneisses, they show no sign of marginal cooling. No one looking at these rocks and those of the Ningi granite could fail to note the marked difference in structure.

Moreover, these Sabon Garri granites may be traced across the Minna River and up to Ningi. Two miles north of that village there is an excellent contact between the Sabon Garri and the Ningi granite. The latter displays chilled margins and the usual contact phenomena.

I fear that the "capable observers who repeatedly traversed"

this area were ignorant of Dr. Falconer's own definitions of the two types of granite.

Finally, as the district was traversed in 1911, why are not these Sabon Garri granites mapped as "projections of younger granite"? They cover a larger area than the Kila granites, which are correctly mapped! Can it be that since Dr. Falconer adopted the theory (*vide* last paragraph in his letter) that tin occurs only in the younger granites, and since the presence of tin *in situ* in the Sabon Garri granites is unquestioned, he has rechristened these rocks to suit the theory?

It is easy to say in what rocks a given mineral does occur, but he would be a foolish man who asserts in what rocks it will not occur. Mineral occurrences are not confined to one age, and Murchison's classic error in regard to the occurrence of gold should not be forgotten. This is a matter of considerable importance. If tin is found only in the "younger granites", then it would be idle to look for it in any of the other rocks, so that, *vide* Dr. Falconer's map, only a very small area offers any prospects for the miner.

When I found tin occurring in granites which agreed with Dr. Falconer's description of the archæan granites associated with the gneisses (and mapped as such by him), I traced one series of these rocks and differentiated them from the normal non-stanniferous type under the name of the Sabon Garri granite.

Believing in the importance of this observation I published it, hoping that other mining men would come forward and describe the country with which they were familiar. By so doing the slight knowledge we have of the stanniferous granites would be widened. Nigeria is a large country, and vastly important as Dr. Falconer's work has been, it is only an outline of the geology of the Protectorate. The details, if they are to be filled in, must be done by the men on the spot who bring forward their notebooks and samples. The mining man is usually fitted to do this work. As a class unacademic in training or thought we make academic errors unconsciously. Witness the premature description of the "younger" granites as Mesozoic in my own "Notes". But on the whole the mining engineer who has preserved his interest in geology makes a good "unskilled labourer" in the field of geology, capable of recording observations and bringing home samples for the benefit of those whose knowledge is infinitely greater but whose opportunities of travel are vastly less. It is in that capacity that I regard my own work, a record of things seen, but not in any way an attempt to raise controversies.

I am sure that the Curator of the Sedgwick Museum would gladly give Dr. Falconer access to any of the slides or specimens so that he may see for himself the types of rock described, especially Nos. 100 and 105.

GERARD W. WILLIAMS.

P.O. Jos.

November 27, 1920.

P.S.—A recent visit to Zelau shows that there is a much greater outcrop of andesitic and rhyolitic rocks in that area than I had previously suspected. There is also an outcrop of a fresh-looking granite which, in the field, resembles the granite exposed in the big creek on the Ex-Lands road, with which Dr. Falconer is familiar. If this granite is shown, on more exact examination than was possible on a flying visit, to be of the younger series, it will be the only case that I have observed of this granite forming a small isolated outcrop. So far I have failed to find any indication of marginal cooling.

I am informed by a mining engineer who knows the Zelau-Begindi-Liuri-Kano country intimately, that outcrops of "younger" granite do occur near to Begindi and at Liuri-Kano. At the latter place they are associated with rhyolites apparently similar to those at the western end of the Ningi Hills. But this observer is, unfortunately, not familiar with the Sabon Garri-Ningi country. His work in the Liuri-Kano area has been thorough and systematic, and I hope that before long he will publish his results, as this country is extremely interesting from a petrological standpoint.

G. W. W.

December 6, 1920.

CARBONIFEROUS *SPIRIFERINA*.

SIR,—In Dr. F. J. North's recently published paper "On *Syringothyris* Winchell and certain Carboniferous Brachiopoda referred to *Spiriferina*, D'Orbigny" (Quart. Journ. Geol. Soc., vol. lxxvi, pt. ii, November 30, 1920), there is a slight error with regard to the locality of the holotype of *Spiriferina perplicata* North (p. 219). This should be Treack Cliff, Castleton (as in "Explanation of Plates"), and not Peak's Hill. I take this opportunity to state that I have presented the holotype of this species (pl. xiii, figs. 7a-c), as well as the figured specimen of *Spiriferina insculpta* (Ph.) (pl. xiii, fig. 11), to the Manchester Museum, where they will be more accessible than in private hands. It is unfortunate that the illustrations of *Spiriferina perplicata* do not do justice to the very distinct lamellose ornament and costation of this species.

J. WILFRID JACKSON.

MANCHESTER MUSEUM.
January 6, 1921.

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MARCH, 1921.

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EDITORIAL NOTES.

AT the Annual General meeting of the Geological Society of London on February 18 last, the officers for the ensuing year were elected as follows: President, Mr. R. D. Oldham (second year of office); Vice-Presidents, Professor E. J. Garwood, Mr. G. W. Lamplugh, Col. H. G. Lyons, and Dr. G. T. Prior; Secretaries, Dr. H. H. Thomas and Mr. W. Campbell Smith; Foreign Secretary, Sir A. Geikie; Treasurer, Mr. R. S. Herries. The new members of the Council are Mr. T. C. Cantrill, Mr. J. A. Douglas, Dr. J. S. Flett, Sir A. H. McMahon, Professor S. H. Reynolds, and Sir A. Strahan.

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AN important representative Committee has been formed to raise a suitable testimonial to Professor Percy Fry Kendall, M.Sc., of the University of Leeds. The Chair of Geology has been occupied by him for thirty years to the great benefit of all those students who have been stimulated by his brilliant and enlightened teaching. He has also done important work in Glacial Geology, and rendered valuable assistance on both the scientific and economic sides of the geology of the Coalfields, in addition to other interesting and useful investigations and the popularizing of geological science by lectures and addresses in Yorkshire and the north of England. Subscriptions should be made payable by cheque or otherwise to the Hon. Treasurer, J. E. Bedford, Esq., F.G.S., Arncliffe, Shire Oak Road, Headingley, Leeds.

* * * * *

By the death of Mr. Charles Edward Fagan, C.B.E., I.S.O., Secretary of the British Museum (Natural History) on January 30, aged 65 years, science has been deprived of the active services of an executive officer who for years past had exerted himself very warmly on behalf of the National Museum. He rendered valuable aid in sending off expeditions to various regions and in obtaining the necessary funds for the publication of the scientific results obtained and ensuring the acquisition and preservation of the new and rare specimens met with. Mr. Fagan entered the Museum in 1873, was made assistant secretary in 1889, and secretary in 1919. He would have retired this spring.

Founders of Seismology.—I. John Michell.

By CHARLES DAVISON, Sc.D.

TO the earthquake that ruined Lisbon on November 1, 1755, we may trace the great interest in the study of earthquakes which marks the middle of the eighteenth century, though valuable accounts of previous earthquakes had already appeared in the pages of the *Philosophical Transactions*. During the following year the Royal Society paid the same close attention to this earthquake that it did more than a century later to those of the eruption of Krakatoa. In 1757 an anonymous editor published *The History and Philosophy of Earthquakes*, in which he gave abstracts of ten memoirs by the "best writers on the subject"—Hooke, Woodward, Buffon, and Stukeley among them—followed by a summary of the observations on the Lisbon earthquake that had been communicated to the Royal Society. These are the principal sources on which Michell depended when he wrote his memoir on the cause and phenomena of earthquakes.¹

The date and place of Michell's birth are unknown, but the year must have been 1724 or 1725, and the place may have been Nottingham. Coming, at any rate, from that city, he entered Queens' College, Cambridge, in 1742, and graduated as fourth wrangler in the second mathematical tripos (1748-9). This success, which but for his wide interests would probably have been greater, was followed by his election to a fellowship at Queens'. His wonderful versatility, even at so early a stage, is shown by his ability to give college lectures on Greek and Hebrew as well as on mathematics. At this time, too, he must have been making those original observations on the structure of the earth's crust, which are described in his memoir on earthquakes. Two years later he was appointed Woodwardian Professor of Geology, being the third holder of that office and the most capable until Sedgwick began his long reign in 1818. In addition to the college tutorship and lectures—there is no evidence that the duties of the professorship were a serious burden—Michell held the rectory of St. Botolph's, Cambridge, from 1760 to 1763. The latter year, however, brought a change, the busy official life at Cambridge giving place to the studious quiet of a country rectory, first at Compton, near Winchester, then at Havant, and lastly, in 1767, at Thornhill, a Yorkshire village not far from Dewsbury. The fellowship at Queens' and the professorship of geology were both vacated in 1764, the year of his first marriage, and no doubt as a

¹ "Conjectures concerning the Cause and Observations upon the Phenomena of Earthquakes; particularly of that great Earthquake of the First of November, 1755, which proved so fatal to the City of Lisbon, and whose Effects were felt as far as Africa, and more or less throughout all Europe." (Read February 28, March 6, 13, 20, 27, 1760.) *Phil. Trans.*, vol. li, 1761, pp. 566-634.

result of that step. In a smaller man such a life might have ended in stagnation, but, with his musical evenings at home, his friendship with many leading men of science, and his frequent visits to London, Michell maintained his freshness, and science rather gained than lost by the change. Happy in his social life, unfailing in the discharge of his parochial duties, and evidently possessing means sufficient for his wants, Michell carried on his scientific work without pause and without hurry, touching nothing that he did not adorn, and careless, apparently, to whom the credit might fall so long as the work was done. He died at Thornhill on April 21, 1793, in his 69th year.¹

Except for his early *Treatise of Artificial Magnets* and his memoir on earthquakes, Michell's work was mainly astronomical. At the age of 25 he discovered the method of making magnets by double touch and the variation of magnetic action according to the inverse square of the distance. Less than ten years later he developed those clear views on stratification that are fully appreciated by modern geologists. Equally original and no less important was his memoir on stellar parallax (1767). In this he insisted on the extreme minuteness of the parallax of even the brightest stars, and inferred that the nearest fixed star is probably no farther from us than 220,000 times the sun's distance—a quite close, if accidental, approximation to the distance of α Centauri. The apparent proper motion of the stars he correctly attributed in part to that of the sun; he estimated the extreme probability that the stars which form the Pleiades constitute a connected system, and he foresaw the discovery, made shortly afterwards by Herschel, of the revolutions of the double stars. At Thornhill he experimented on the best alloys for the mirrors of reflecting telescopes and on the method of giving the mirrors their proper form. The 10 ft. reflector which he made was afterwards bought and used by William Herschel. Michell also invented the torsion-balance, and devised a method for determining the density of the earth. The apparatus was completed a short time before his death, but he did not live to make any experiment with it. It passed ultimately into the capable hands of Henry Cavendish, and led to his well-known determination of the density of the earth. Michell, like Darwin, was evidently one of those men who "seemed by gentle persuasion to have penetrated that reserve of nature which baffles smaller men". Is it too much to claim for him a place, not, indeed, beside Newton and Darwin, but in a rank not so very far below them?

During his own life Michell's extraordinary power was known and valued. Among his friends he could number such men as Cavendish, Black, Priestley, and William Herschel. It is all the stranger, then, that his memoir on the cause and phenomena of

¹ The above biographical details are derived chiefly from articles in the *Dictionary of National Biography*; the *English Mechanic*, vol. xiii, 1871, pp. 309-10; *Knowledge*, vol. xv, 1892, pp. 188-91, 206-8; and Sir A. Geikie's *Memoir of John Michell* (Camb. Univ. Press), 1918.

earthquakes should have remained, or appeared to remain, practically unknown for more than half a century. It was referred to in an article in the *Edinburgh Review* for February, 1818, and later in that year was reprinted, with notes by John Farey, sen., in the *Philosophical Magazine*.¹ Many years after his death, full, if belated, justice has been done to Michell's stratigraphical conceptions; but his work, so far as it deals with earthquakes, is less well known, owing partly perhaps to the inaccurate account which Mallet gave of it in his early memoirs.²

Leaving out of account the important section on the nature and trend of strata—a section which has been adequately dealt with by Sir A. Geikie and others—Michell's paper may be divided into three parts. In the first he describes the phenomena of earthquakes, in the second he explains in detail his theory of their cause, and in the third he gives methods for determining the position of the seismic focus.

The Phenomena of Earthquakes.—Like his predecessors, Michell begins with a summary of the phenomena which his theory must explain; but, unlike them, he distinguishes between certain phenomena which are essential to, and others which have no connexion with, the origin of earthquakes. The latter are what we now call secondary or mechanical effects of the shock, such as the sudden stopping and gushing out of fountains occasioned by the opening or contraction of fissures, the dizziness and sickness induced by the wave-like motion, and the disturbances sometimes occasioned in the direction of the magnetic needle. These are not "observed to be constant attendants on earthquakes, nor do they seem materially to affect the solution given one way or other". The phenomena which Michell regarded as essential, five in number, are the following:—

(i) The same places are subject to returns of earthquakes, not only at small intervals for some time after any considerable one has happened, but also at greater intervals of some ages. Michell thus distinguishes between the occurrence of after-shocks and the returns of great earthquakes, as he shows by his reference to the 451 shocks felt at Lima from October 28, 1746, to February 24, 1747, and to the sixteen very violent earthquakes at the same place from 1582 to 1746.

(ii) Those places that are in the neighbourhood of burning mountains are always subject to frequent earthquakes, and the eruptions of those mountains, when violent, are generally attended by them. Michell refers especially to Peru and Chile, no other known countries, he supposes, being so subject to earthquakes and none so full of volcanoes.

¹ Vol. lii, 1818, pp. 186–95, 254–70, 323–40.

² *Trans. Irish Acad.* (read 1846), vol. xxi, 1848, pp. 58–60, 65–7, 84–5; also *Rep. Brit. Assoc.*, 1850, pp. 17–19.

(iii) The motion of the earth in earthquakes is partly tremulous and partly propagated by waves, which succeed one another sometimes at larger, sometimes at smaller, distances; and this latter motion is generally propagated much farther than the other. The former part of this statement, Michell considers, "wants no confirmation." Indeed, his explanation of the manner in which the vibrations are propagated through the solid crust is quite as clear as that given by Mallet nearly a century later. In illustration of the latter, he quotes accounts of what are now called "visible waves", such as that of an observer of the Jamaica earthquake of 1688, who "saw the ground rise like the sea in a wave as the earthquake passed along, and" who "could distinguish the effects of it to some miles distance by the motion of the tops of the trees on the hills". In the Lisbon earthquake "this wave-like motion was propagated to far greater distances than the other tremulous one, being perceived by the motion of waters and the hanging branches in churches through all Germany . . . in Denmark, Sweden, Norway, and all over the British Isles".

(iv) It is observed in places which are subject to frequent earthquakes that they generally come to one and the same place from the same point of the compass. Also the velocity with which they proceed (as far as one can collect it from the accounts of them) is the same; but the velocity of the earthquakes of different countries is very different. Michell's illustration of the latter statement, though not quite accurate, is interesting. The velocity with which the Lisbon earthquake and its after-shocks were propagated "was the same, being at least equal to that of sound; for all followed immediately after the noise that preceded them, or rather the noise and the earthquake came together"; that of the New England earthquakes was less, as is shown by the longer interval between the preceding noise and the shock.¹

(v) The great Lisbon earthquake was succeeded by several local ones (in Switzerland and elsewhere), the extent of which was much less.

The Cause of the Earthquakes.—Long before Michell's time, it was "the general opinion of philosophers that earthquakes owe their origin to some sudden explosion in the internal parts of the earth".² Michell traces earthquakes to the primary cause to which they also appeal, namely, subterranean fires. He differs from his predecessors chiefly in his endeavour to support this theory by facts and to trace out the effects of such explosions. "These fires," he says, "if a

¹ From records of the time of the great earthquake at Lisbon and more distant places, Michell estimates the velocity at more than 20 miles a minute. This is the earliest estimate of the kind known to me.

² The following sentence is worth quoting from *The History and Philosophy of Earthquakes* (p. 26), as it refers to probably the earliest instance of a seismic experiment: "Honoratus Faber illustrates this doctrine by a variety of artificial earthquakes, as he calls them, confining gunpowder (a mixture of nitre, sulphur, and charcoal) in pits, and setting fire to it by a train."

large quantity of water should be let out upon them suddenly, may produce a vapour whose quantity and elastic force may be fully sufficient for the purpose." Indeed, he remarks, "it is not easy to find any other cause capable of producing such sudden and violent effects."

The fires to which he refers are of the same kind as the fires of volcanoes, but, like Humboldt after him, Michell regards the volcanic fires as safety-valves, "for volcanoes, giving passage to the vapours that are thus formed, should rather prevent" earthquakes. If it should be asked why we should suppose that subterraneous fires exist in the neighbourhood of volcanoes, Michell points to the frequent instances of new volcanoes breaking out near old ones, to the existence of many volcanoes close together in the same tract of country, and to the rarity of isolated volcanoes.

Michell regards it as very probable that the fires of volcanic regions originate in a stratum, like coal or shale, in which pyrites is lodged in such quantity that it will inflame of itself, but that the quantity varies in different parts of the stratum so that the fires are not continuous. The same strata, he remarks, are generally very extensive, and they commonly lie more inclining from the mountainous countries than the countries themselves. "These circumstances make it very probable that those strata of combustible materials which break out in volcanoes at the tops of the hills are to be found at a considerable depth under ground in the level and low countries near them. If this should be the case, and if the same strata should be on fire in any places under such conditions, as well as on the tops of hills, all vapours, of whatsoever kind, raised from these fires must be pent up, unless so far as they can open for themselves a passage between the strata; whereas the vapours raised from volcanoes find a vent, and are discharged in blasts from the mouth of them. Now, if when they find such a vent they are yet capable of shaking the country to the distance of ten or twenty miles round, what may we expect from them when they are confined?" Thus, "the most extensive earthquakes should take their rise from the level and low countries, but more especially from the sea, which is nothing else than waters covering such countries."

The manner in which the water contained in fissures reaches the subterraneous fires below is explained at some length, but in parts with less than Michell's usual clearness. He supposes the roof over a subterraneous fire to fall in. "If this should be the case, the earth, stones, etc., of which it was composed, would immediately sink in the melted matter of the fire below; hence all the water contained in the fissures and cavities of the part falling in would come in contact with the fire and be almost instantly raised in vapour." The fall of the roof, Michell admits, could not happen accidentally. He connects it with the expansion of the matter of which the subterraneous fire is composed, by which the roof is gradually raised and bent until collapse takes place.

He then proceeds to show how his theory will account for the various phenomena described above. The return of earthquakes to the same place is to be expected, for, as in volcanoes, the subterraneous fires may be supposed to subsist for many ages. Moreover, as volcanoes frequently rage for a time and then are quiet for a number of years, so we see earthquakes frequently repeated for some small time and then ceasing for a long period, except perhaps for the occurrence now and then of some slight shock. The great frequency of earthquakes in the neighbourhood of burning mountains is a strong argument of their proceeding from a cause of the same kind.

The two forms of motion which Michell so clearly discerned in earthquakes are consequences, in his view, of the varying amount of the vapour generated. A small quantity of vapour almost instantly generated would produce the vibratory motion; a very large quantity would result in a wave-like motion.

The first effect of the vapour, he says, would be to form a cavity between the melted matter and superincumbent earth by the compression of the materials immediately over the cavity, and "this compression must be propagated on account of the elasticity of the earth, in the same manner as a pulse is propagated through the air; and again the materials immediately over the cavity, restoring themselves beyond their natural bounds, a dilatation will succeed to the compression; and these two following each other alternately for some time a vibratory motion will be produced at the surface of the earth. If these alternate dilations and compressions should succeed one another at very short intervals, they would excite a like motion in the air, and thereby occasion a considerable noise. The noise," he adds, "that is usually observed to precede or accompany earthquakes is probably owing partly to this cause, and partly to the grating of the parts of the earth together, occasioned by that wave-like motion before mentioned."

Michell illustrates the propagation of the wave-like motion by describing an experiment which has led to some misconception of his views. "Suppose a large cloth or carpet (spread upon a floor) to be raised at one edge and then suddenly brought down again to the floor, the air under it, being by this means propelled, will pass along until it escapes at the opposite edge, raising the cloth in a wave all the way as it goes. In like manner, a large quantity of vapour may be conceived to raise the earth in a wave, as it passes along between the strata, which it may easily separate in an horizontal direction, there being . . . little or no cohesion between one stratum and another. The part of the earth that is first raised, being bent from its natural form, will endeavour to restore itself by its elasticity, and the parts next to it, beginning to have their weight supported by the vapour which will insinuate itself under them, will be raised in their turn, till it either finds some vent or is again condensed by the cold into water, and by that means prevented from proceeding any further."

Equally interesting, and less open to objection, is Michell's explanation of the propagation of the wave-like motion to distances far greater than the vibratory motion. This motion, he states, "will be propagated through the solid parts of the earth, and, therefore, it will much sooner become too weak to be perceived than the wave-like motion, for this latter, being occasioned by the vapour insinuating itself between the strata, may be propagated to very great distances; and even after it has ceased to be perceived by the senses it may still discover itself by the appearances before mentioned." That is to say, in modern terms, the wave-like motion is propagated in two and the vibratory motion in three dimensions.

All earthquakes derived from the same subterraneous fire must come to any place in the same direction. Those only which are derived from different fires will come from different points of the compass. Moreover, since, according to Michell, the velocity with which the vapour insinuates itself between the strata depends upon its depth below the surface, earthquakes must travel with the same velocity if they proceed from fires at different depths. The occurrence of local earthquakes in other places Michell accounts for by supposing that the vapour coming from one fire may disturb the roof over some adjacent fires, and so occasion earthquakes by the falling in of some part of it.

Michell also suggests explanations of two other phenomena besides those described above. These are the great sea-waves and "a sort of periodical return" of earthquakes in the same region. The first movement of the sea at Lisbon was, as usual, a retreat of the water followed by the inrush of the great waves. During the elevation of the roof over the subterraneous fire the waters of the ocean lying over it must retreat, but so slowly and so gently as to occasion no great disturbance. But as soon as one part of the roof falls in "the cold water contained in the fissure of it, mixing with the steam, will immediately produce a vacuum, in the same manner as the water injected into the cylinder of a steam-engine, and the earth subsiding, and leaving a hollow place above, the waters will flow every way towards it and cause a retreat of the sea on all the shores round about; then, presently, the waters being again converted by the contact of the fire into vapour . . . the earth will be raised, and the waters over it will be made to flow every way and produce a great wave immediately succeeding the previous retreat."

Lastly, the great quantity of water let out upon the subterraneous fire "must extinguish a great portion of the burning matter, in consequence of which it will be contracted within much narrower bounds", and this will continue "till the roof is well settled and the surface of the melted matter sufficiently cooled, after which it may require a long time for the fire to heat it again so much as will be necessary to make it produce the former effects".¹

¹ At the end of the section on stratification Michell gives the following paragraph: "Besides the rising of the strata in a ridge, there is another very

The Position of the Epicentre.—In the last section of his memoir, Michell shows that “if we would inquire into the place of the origin of any particular earthquake, we have the following grounds to go upon :—

(i) “The different directions in which it arrives at several distant places; if lines be drawn in these directions the place of their common intersection must be nearly the place sought; but this is liable to great difficulties, for there must necessarily be great uncertainty in observations, which cannot, at best, be made with any great precision, and which are generally made by minds too little at ease to be nice observers of what passes; moreover, the directions themselves may be somewhat varied by the inequalities in the weight of the superincumbent matter, under which the vapour passes, as well as by other causes.

(ii) “We may form some judgment concerning the place of the origin of a particular earthquake from the time of its arrival at different places, but this also is liable to great difficulties. In both these methods, however, we may come to a much greater degree of exactness by taking a medium amongst a variety of accounts as they are related by different observers. But,

(iii) “We may come to the greatest degree of exactness in those cases where earthquakes have their source from under the ocean; for in these instances the proportional distance of places from that source may be very nearly ascertained by the interval between the earthquake and the succeeding wave, and this is the more to be depended on as people are much less likely to be mistaken in determining the time between two events which follow one another at a small interval than in observing the precise time of the happening of some single event.”

The first method is that which Mallet applied with such skill in his study of the Neapolitan earthquake of 1857, though he depended on more permanent evidences of the direction than the impressions of observers. The third method is, of course, vitiated by the assumption that the velocity of sea-waves is independent of the depth of the ocean, but the greater accuracy attainable by measuring intervals rather than absolute times lies at the root of the method depending on the duration of the preliminary tremor which is now so widely used.

remarkable appearance in the structure of the earth, though a very common one; and this is what is usually called by miners the trapping down of the strata; that is, the whole set of strata on one side such a cleft are sunk down below the level of the corresponding strata on the other side. If, in some cases, this difference in the level of the strata on the different sides of the cleft should be very considerable, it may have a great effect in producing some of the singularities of particular earthquakes.” One cannot help regretting the brevity of Michell’s statement on the relations between earthquakes and faults. I can only suggest that, according to his view, the vapour, in travelling outwards by parting adjacent strata, would be suddenly arrested at the fault.

In locating the origin of the Lisbon earthquake Michell relies on other evidence rather than on the methods which he describes so clearly. The great sea-wave which followed the earthquake indicates that the origin was submarine, and it could not be far from Lisbon, as the wave arrived there so soon after the earthquake and was of such great height. It must, he thinks, lie somewhere between the latitudes of Lisbon and Oporto, though probably somewhat nearer to the former (about a degree of a great circle, he afterwards assumes, from Lisbon and a degree and a half from Oporto), and at a distance of 10 or 15 leagues from the coast. Such a position agrees well with the few observations which he possessed on the direction and time of the earthquake. But, curiously enough, he notices that "the times which the wave took up in travelling are not in the same proportion with the distances of the respective places from the supposed source of the motion". He does not, however, regard this as an objection to the point assumed, but thinks—and here he foresaw a later discovery—that "the true reason of this disproportion seems to be the difference in the depth of the water; for in every instance in the above table the time will be found to be proportionately shorter or longer as the water through which the wave passed was deeper or shallower".

The methods which Michell suggests for inquiring "into the depth at which the cause lies that occasions any particular earthquake" depend on his theory of the origin of earthquakes, and need not be here described. For the Lisbon earthquake the observations required in order to apply the methods did not exist. But "if", he says, "I might be allowed to form a random guess about it I should suppose (upon a comparison of all circumstances) that it could not be much less than a mile or mile and a half, and I think it is probable it did not exceed three miles."

Conclusion.—With our fuller knowledge it would be an easy matter to criticize Michell's theory of the cause of earthquakes. I do not propose to enter now on such a task, my object being rather to give a brief summary of his contributions, which seem to me to possess a permanent value.

In the first place must be mentioned his distinction between the phenomena which are essential and those which are not essential to his theory. In separating the vibratory motion from the wave-like motion, Michell was in advance of his time. He was one of the first, if not the very first, to assign the vibratory motion in earthquakes to the propagation of elastic waves in the earth's crust.

In the second place he rendered an important service in his attempt to give a consistent theory of the origin of earthquakes, even if the theory, as we can now see, rests on an erroneous conception of volcanic action, and if it cannot explain all the phenomena that have since been discovered. His suggestions as to the origin of earthquake sounds and of seismic sea-waves would seem, in part, at any rate, to be correct.

Lastly Michell devised two useful methods for determining the position of the epicentre. Both were afterwards overlooked and both have been reinvented and applied with varying success to the investigation of earthquakes. Michell's "random guess" as to the depth of the focus, like Newton's guess with regard to the density of the earth, is one of those intuitions that occur only to the ablest minds.

Michell evidently failed to impress his readers, and "he who succeeds in doing so", says Darwin, "deserves in my opinion all the credit." But what if the failure be the fault of his readers—not of his contemporaries, for it was chiefly to this memoir that Michell owed his election to the Royal Society, but of their successors? If Michell's conceptions of the form and trend of strata could sink into temporary oblivion, it is not surprising that his almost prophetic insight into earthquake phenomena should share their fate. But if his influence on future workers were less than his memoir deserves he does not, I think, forfeit his claim to be regarded as one of the Founders of Seismology.

ORIGINAL ARTICLES.

On Cycles of Sedimentation in the Eocene Strata of the Anglo-Franco-Belgian Basin.¹

By L. DUDLEY STAMP, M.Sc., A.K.C., F.G.S., King's College, London.

I. INTRODUCTION.

THE term "Cycle of Sedimentation" or "Cycle of Deposition" is not nearly so familiar in England as it is on the Continent. Whilst the teaching of the general principles forms part of most courses in geology, the application of these principles to actual successions in this country has been somewhat neglected. Attention has recently been drawn to the seasonal or rhythmic changes seen in some sediments, and to avoid confusion it is desirable to outline what is meant by the expression "Cycle of Sedimentation".

If one considers a sea transgressing over a steadily sinking land, the first stage in its progress will be marked by coarse, conglomeratic deposits of coastal (not necessarily beach) origin. This basal "conglomerate" is the "gravier d'immersion" of French authors. It passes laterally in a seaward direction into sands and finer deposits. In a later stage the coastal deposits will overstep the former, and deeper-water sediments—sands and clays—be laid down in direct succession to the coastal deposits of earlier date. This process continues during the transgression, and so in deposits of a simple overlap of this nature one has, at any point, a vertical transition from pebble-beds through coarse sands to finer sands and clays. That the basal conglomerates are not of the same age throughout is proved by a study of the faunas. One finds a palæontological zone to pass laterally from clays into sands and coarse sands and probably into the coastal pebble-beds. Such zones are represented in the diagram (Fig. 1) by horizontal layers marked Z 1, Z 2, Z 3, etc.

When the transgressive movement of the sea ceases there is generally a tendency for the basin to become "silted up". This is especially the case when quantities of sediment are being brought into the basin from adjacent continental areas. In the neighbourhood of a delta one finds that the marine deposits pass gradually upwards into estuarine beds with a brackish-water fauna. These are succeeded in turn by lagoon (brackish or fresh water), lacustrine, fluvatile, or even æolian deposits. For the sake of brevity, all sediments of this nature, that is, other than marine, are referred to as *continental*.

In other parts of a basin of deposition where little sediment is being received from continental sources, the shallowing or, it may be,

¹ Paper read before Section C (Geology) of the British Association for the Advancement of Science, Cardiff Meeting, August, 1920.

retreat (regression) of the sea is marked by a recurrence of coarser sediments—silt and sands—culminating possibly in conglomerate (“*gravier d’émersion*”).

The succeeding marine invasion may remove a portion of the continental or coastal deposits, the coarse or hard materials being rearranged to form a new “*gravier d’immersion*” or basal conglomerate. This frequently includes rolled fragments of fossils, etc., derived from the underlying beds. Where the latter are fine-grained or unconsolidated, the “*gravier d’immersion*” may be feebly developed and inconspicuous, but the plane of erosion between the new marine deposits and the underlying beds, whether of continental or marine origin, is almost invariably well-marked. In other words there is a “*ravinement*” at the base of each marine formation.¹

The period between two successive “*ravinements*” constitutes a “cycle of sedimentation”. In other words, a “cycle of sedimentation” comprises the deposits of a complete oscillation of the basin, each oscillation including a positive phase of marine invasion and a negative phase of regression.

The deposits of the second marine invasion form a series closely comparable with the first. The invasion may be more or less extensive than the earlier, and the seaward range of the continental deposits more restricted or less so.

Fig. 1 is a diagrammatic representation of the deposits of three complete cycles of sedimentation. The section is drawn from the landward edge of a basin towards the centre. The relative extent of marine and continental deposits is seen at a glance. Taking the upper or lower limit of the zones as representing approximately time planes, it is apparent that each basal conglomerate is not of the same age over its whole extent. That is, the cycle does not commence at exactly the same time at each point. Yet, as many authors have recognized, the only possible grouping of such deposits is by cycles. The changes at any particular locality during a series of cycles may be represented graphically. Taking a straight line to represent sea-level and regarding, for the sake of clearness, all continental deposits as having been formed above sea-level, the oscillations of the land surface at any one point may be represented by a curve. This graphical representation is important in that it emphasizes the time factor. Two examples, for the points *A* and *B*,

¹ A “*ravinement*” may be defined as an irregular junction which marks a break in sedimentation. The break may be due to a period of denudation consequent on movements of masses of water, but not necessarily accompanied by earth-movements. Although one of the commonest of geological phenomena, there is no English word which expresses quite so aptly the relationship. One may say that there is an “unconformity” at the base of the marine formation, but that term rather suggests discordance of stratification and earth-movements of a more pronounced character. The term “plane of erosion” is bad, since the basal conglomerate tends to occupy an irregular or hummocky surface of the underlying deposits rather than a plane surface. “Non-sequence” is most frequently applied to a break in sedimentation which can be detected only by a study of successive faunas.

are given in Fig. 1. One sees immediately the comparative duration of the cycles, the relative duration of the marine and continental periods in each and the approximate depth of formation of the deposits. By comparison of two or more graphs, using well-marked

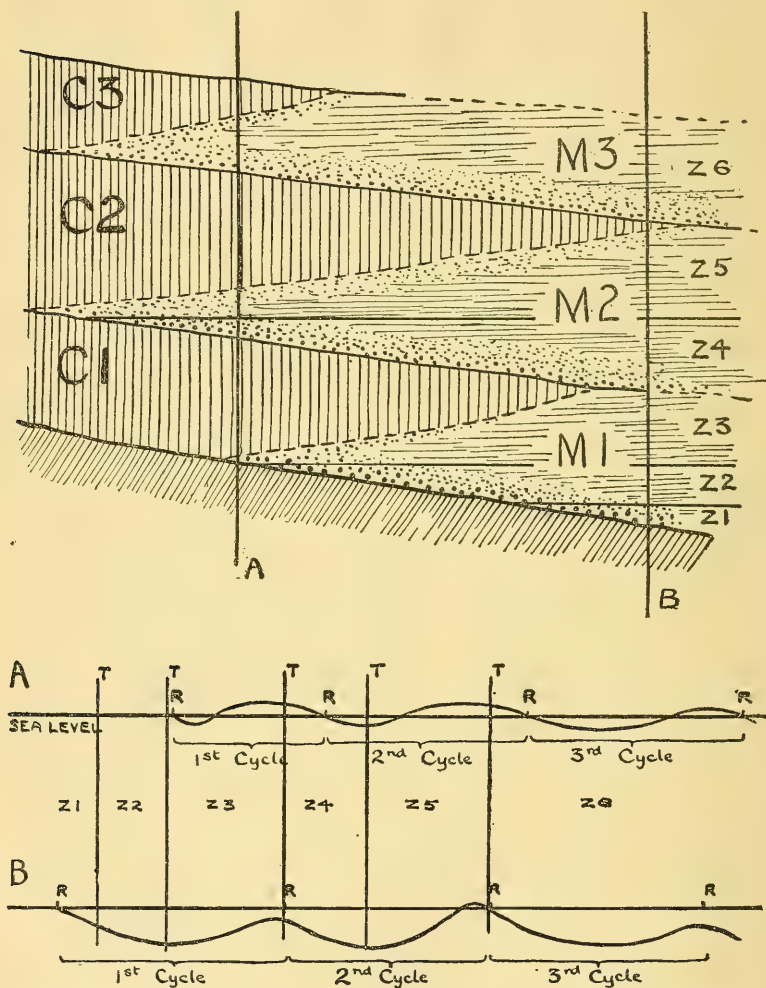


FIG. 1.—Diagrammatic representation of three cycles of sedimentation. M = marine deposits, showing gradation in coarseness. C = continental deposits. Z = zones, as determined by palæontology. The two graphs show the oscillations of the land surface relative to sea-level at the points A and B. R = position of "ravinements". T = junction planes between zones, used as time planes to show the relative time of commencement of each cycle at the points A and B.

palæontological horizons as time planes, one can trace the relative time of commencement of each cycle in different places.

In an enclosed or partly enclosed basin it is not difficult to see that intermittent earth movements would cause oscillations in the water-level and give rise to a series of cycles of sedimentation. As will be seen later, this is precisely the condition of formation of the Eocene strata of the Anglo-Franco-Belgian region. Each movement caused a marine transgression, which was followed naturally by silting up and retreat of the sea.

In a broad sense and on a large scale the importance of the sedimentary cycle has long been recognized. It is the *raison d'être* of most of the systems before they received more exact palæontological definition. Professor Watts, in his Presidential Address to the Geological Society in 1911,¹ has dealt exhaustively with the sequence of deposition. Commencing with abysmal deposits he has traced the changes through shallow-water and littoral sediments to beds deposited during emergence, then the beds formed during a succeeding submergence, passing finally back to abysmal deposits. This is a simple way of presenting the sequence, but it must be borne in mind that the natural period commences with the unconformity at the base of the marine beds (i.e. coinciding with a submergence of the land), and the abysmal deposits occupy the middle period of the cycle, its termination being marked by the continental deposits and finally abruptly limited by the succeeding marine invasion.

The application of these principles to detailed classification on a small scale has been given primary consideration on the Continent. One may quote the work of the Geological Survey of Belgium. The nomenclature and grouping used on the maps indicate at once the importance attached to it. Each formation is given an index letter, and the deposits in each formation are marked by a second letter. Taking, for example, the Ypresian (London Clay) Series, one has the following divisions :—²

- Ye. Littoral deposits ("gravier d'émergence").
- Yd. Sand indicating shallowing conditions.
- Yc. Clay (main mass).
- Yb. Sand of basement bed.
- Ya. Basal conglomerate ("gravier d'immersion").

The bed "e" in most cycles is removed before the deposition of succeeding strata. In the Belgian classification the continental deposits generally receive a separate index letter. In some cases, however, a bed which does not fit in the main series is given the distinguishing letter "m" or "n", etc. For example, at the base of the "Paniselian" there is a stiff blue unfossiliferous clay,

¹ Watts, "Geology as Geographical Evolution": *Quart. Journ. Geol. Soc.*, vol. lxxvii, 1911, p. lxii.

² "Légende de la Carte géologique de Belgique . . . à l'Echelle du 40,000^e", 1891, etc.: Review in *Ann. Soc. géol. Belg.*, vol. xix, 1891, p. 107.

frequently regarded as of lagoon origin; this is called *P1m*, the Paniselian having been divided into two cycles, *P1* and *P2*. It seems probable that this scheme of nomenclature has been carried too far by the Belgian Survey, for example in the Devonian, where the artificial grouping of the deposits of each division (Coblentzian, etc.) has obscured the more or less continuous marine transgression of Lower Devonian times. However, even there it has the advantage of giving some indication of the lithology of the beds, by a single symbol.

The application of the principle to the classification of the Eocene strata of the Paris Basin is due especially to Professor Leriche.¹ As will be seen later these deposits are especially suitable for classification in this way.

II. THE ANGLO-FRANCO-BELGIAN BASIN.

The Eocene rocks of the area under consideration occur in four principal districts—the so-called “Basins” of Paris, Northern France and Belgium, London, and Hampshire. Separating these four areas of Eocene rocks there are uplands of Cretaceous or older rocks. It is now quite certain that they are not original basins of deposition, but formed part of one great basin—the Anglo-Franco-Belgian Basin. The folding which has affected this extensive area and caused its separation into the present “basins” took place, for the most part, in post-Eocene times. One finds, for example, in the monocline of the Isle of Wight² and the anticline of the Pays de Bray³ that the Eocene beds are involved in the movements. Their thickness is quite independent of the folding. Hence it may be inferred that the movements did not *commence* until after Eocene times. On the other hand, there is a large amount of evidence that the uplift of the Wealden Dome commenced even before Eocene times, and went on gradually throughout the early Tertiary period. The effects of the movement can be clearly seen in the character of the Eocene deposits of the London Basin. The areas of uplift between the present “basins” have been stripped by denudation of their Eocene rocks, and only a few scattered outliers remain to indicate the former continuity of the deposits.

The Paris Basin is situated mainly to the north of Paris. Southwards the Eocene series becomes incomplete, since some of the marine invasions did not penetrate beyond the latitude of Paris. The Paris Basin is separated from the Eocene region of Northern France and Belgium by the Chalk uplands of Artois, Picardy, and Champagne, and one only finds a few patches of Lower Eocene rocks from the

¹ Leriche, “Observations sur la Classification des assises paléocènes et éocènes du Bassin de Paris”: *Ann. Soc. géol. Nord*, vol. xxxiv, 1905, p. 383.

² Bristow, *Geology of the Isle of Wight* (Mem. Geol. Surv.), 2nd ed., 1889, p. 242.

³ Dollfus, “Essai sur la détermination de l'âge du soulèvement du Pays de Bray”: *Bull. Soc. géol. France*, sér. III, vol. ix, 1881, p. 112.

neighbourhood of Laon to the neighbourhood of Lille. In the drift and clay-with-flints which partly covers the Chalk, however, Leriche has found fossiliferous remanié blocks proving the former presence of all the Eocene deposits.¹

In Belgium Eocene rocks occupy the whole of the northern and western parts of the country, and this "basin" extends into the adjoining regions of Northern France. It stretches northwards into Holland, but the Eocene rocks are there covered by a great thickness of later deposits. To the south-east the Ardennes apparently formed an area of dry land during most of the Eocene period, and the deposits tend to assume a littoral character as they are traced in this direction.

On the extreme west of the North France-Belgium region, near Calais and St. Omer, the succession is so similar to that on the opposite side of the Straits of Dover in the Isle of Thanet and near Herne Bay that there seems little doubt concerning the former continuity of the deposits. One sees, resting on the Chalk, the glauconitic marine Thanet Sands (Landenian) with harder beds ("tuffeau") in the lower part and the "Bullhead Bed" of green-coated, unrolled flints at the base, both near Ramsgate and St. Omer. The succeeding Ypresian commences at Reculvers (Herne Bay)² with a pebble-bed and about 20 feet of very fine brownish sand (Oldhaven Sand), followed by the great mass of stiff blue clay (London Clay). Around Calais³ there is the same succession—first the pebble-bed, then the bed of very fine brownish sand, and then the great mass of London Clay (Argile yprésienne). Moreover, the faunal evidence corroborates the lithological.

The London Basin is too well-known to need any introductory remarks. There is every reason to believe that the Hampshire Basin was originally joined to the extreme western end of the London Basin. The existence of a few small outliers as well as relict blocks ("sarsens") on the intervening Chalk lands and the close lithological resemblance between the two areas are sufficient proof. The central portion of the Wealden Dome probably formed an island of low relief or a submerged area within the reach of wave action during the greater part of Eocene times.

The outliers at the eastern end of the Hampshire Basin, especially at Newhaven, form a connecting link with the small outliers on the other side of the Channel near Dieppe. In many respects the Eocene beds of Dieppe resemble the Hampshire deposits more clearly than they do the Paris deposits. Not only are the Dieppe deposits

¹ Leriche, *Ann. Soc. géol. Nord*, vol. xxxii, 1903, pp. 120, 239; vol. xxxviii, 1909, pp. 74, 421. *C.r. Ass. Franç. Avan. Sci.*, Cherbourg, 1905, p. 394; *ibid.*, Lille, 1909, p. 408. *Bull. Soc. géol. France*, sér. iv, vol. xii, 1912, p. 690 et seq.

² Whitaker, *Geology of the London Basin* (Mem. Geol. Surv.), vol. iv, 1872, p. 170, etc.

³ Briquet, "Observations sur la Composition des Terrains Eocènes inférieurs du Nord de la France": *Ann. Soc. géol. Nord*, vol. xxxv, 1906, p. 132.

connected with the main part of the Paris Basin by a large number of outliers, but along the shores of the English Channel there are other outliers (at St. Valéry-sur-Somme, Montreuil, etc.), forming a connecting chain with the deposits of Northern France.

Summarizing the geographical conditions in the whole region at the time of formation of the Eocene strata, there was a single large basin stretching from Norfolk on the north to beyond Paris on the south, and from Devonshire on the west to the Limburg (Eastern Belgium) on the east. This basin may have been enclosed, but was more probably open to the north-east. Sediment was being poured into it from two principal sources—by a great river flowing eastwards into the basin in the London and Hampshire regions, and by another river emptying northwards in the Paris region. Subsidiary sources of sediment probably lay to the east in Belgium. It is hoped that a study of the detrital minerals, at present being carried out by the author, will throw further light on this subject. Throughout the period the basin was subjected to earth-movements, of which the gradual but intermittent uplift of the Wealden Dome seems almost certainly to have been one result. This caused a periodic transgression and regression of the marine waters of the basin, and so it is only in the centre that one would expect to find a succession of marine deposits. Round the periphery one should have, if conditions for preservation were ideal, a succession of continental deposits. Over the greater part of the whole region one has a succession of marine and continental deposits in regular alternation, and the beds can be grouped naturally into a series of cycles of sedimentation. As will be shown later, the same cycles are traceable over the whole basin, and it is essential to consider the four areas—France, Belgium, London, and Hampshire—as a single region.

(To be continued.)

The Relative Age of Concretions.

By W. ALFRED RICHARDSON, M.Sc., B.Sc. (Eng.), F.G.S.

I. THE RELATIVE AGE.

THE age of a concretion, relative to that of the parent-rock, must be either :—

1. *Contemporaneous*.—The concretion grew on the sea-floor at the same time, and at about the same rate, as the surrounding deposit was laid down.

2. *Penecontemporaneous*.—The concretion segregated more or less close to the surface of recently deposited sediment.

3. *Subsequent*.—The concretion formed after deposition had finished, and after the strata had largely consolidated, but, perhaps, before cementation had taken place to any noteworthy extent.

Further, if the concretion were formed subsequently to the main deposit its attitude to the mother-rock must have been either :—

(a) *Displacive*. The original material has been pushed aside to make room for the later.

Or (b) *Replacive*. The original material has been carried away in solution, and the new deposited progressively in its place.

There is also the possibility that a replacive concretion may cause some displacement of the strata, if its volume be greater than that of the original material.

Workers who wish to determine the relative age of segregations appeal mainly to facts gathered by field and microscopic study. Yet it is safe to say there is hardly a class of fact that has not been adopted by advocates of both contemporaneous and subsequent origin in support of their very different contentions. It is surprising on this account that no attempt to examine critically the significance of fundamental tests of relative age appears to have been made.

II. BENDING OF LAMINATION PLANES.

The bending of planes of lamination so that they conform to the shape of a concretion is often reported. Some observers consider this feature a proof of the secondary displacement of the strata;¹ whilst others see in it only evidence of the resistance of an object, harder than the main deposit, to the weight of overlying material.²

On reflection, however, it will be seen that there are three distinct ways by which such a structure may have arisen, namely:—

1. Accumulation of sediment in layers over a contemporaneous segregation.

2. Differential consolidation of the sediment in the neighbourhood of a contemporaneous segregation.

3. Progressive displacement of rock-layers by a subsequent concretion.

The effect of sedimentation may be considered before the other possibilities. The arrangement of successive layers with respect to an object already on the sea-floor will be determined largely by the following factors:—

1. Gravitation.

2. The angle of repose of the material—a measure of its internal friction in water.

3. The sensitiveness of the deposit to water-currents.

4. Friction between the object and the deposit.

The last is doubtless negligible as its influence is theoretically limited to a layer one particle thick, and beyond only the internal friction between particles of the deposit comes into play.

The general operation of these factors was made the object of simple experiments. A rectangular glass vessel was provided with a plasticene floor, the slope of which to the horizontal could be varied readily by tilting the vessel. Two types of material were used, and the results may be summarized thus:—

¹ Dean, *Amer. Journ. Sci.*, vol. xlv, 1918, p. 411.

² Gardner, *ibid.*, vol. xvi, 1908, p. 457.

1. A flocculent precipitate, obtained by the addition of ammonia water to a solution of an aluminium salt, had a very low angle of repose, but settled in still water along the flatter slopes. The slightest movement of the water, such as that due to a gentle tapping of the vessel, caused immediate settlement of the precipitate to a level surface.

2. Fine silver sand had a greater angle of repose, and also required a much stronger water-movement to level it.

3. There was no tendency for either of these to adhere to the plasticene surface. When the deposit accumulated along the slope in still water the layer as might be expected was thicker at the base.

Snow may be frequently seen to heap up over objects. But it does so permanently only when partial melting and refreezing have welded it into something like a continuous sheet. A slight breeze is sufficient to blow dry, powdery snow from elevated objects, and it then settles into drifts, the shape of which is determined chiefly by wind-eddies and the protection afforded by surrounding objects.

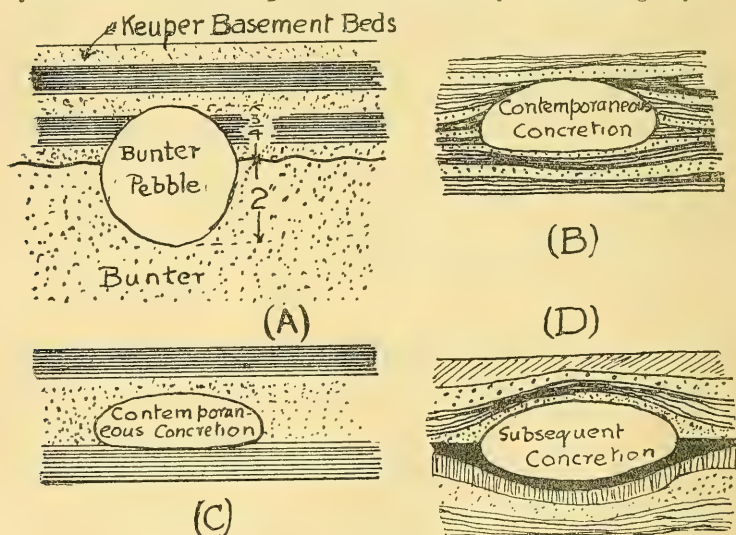


FIG. 1.—(A) Type of sedimentation around a contemporaneous object; laminae thinner than object. (B) Similar to (A), but laminae thicker than object. (C) Vertical loading on contemporaneous concretion producing "catenary" bedding. (D) Conformity of bedding planes to subsequent concretion, produced by displacement during growth.

In any case the density and viscosity of such a medium as water would, when in motion, be more effective than air in bringing loose material to a gravitational surface. Ample confirmation of this is afforded by the examination of stream beds, pools, and shore margins. Boulders and other objects stand clear even of a sandy deposit, for,

although possessing a large angle of repose, sand occurs in zones of relatively strong movement

A further example is afforded from the Nottingham district, where pebbles frequently project from the wind-eroded surface of the Bunter into the overlying, laminated, Keuper sands.¹ Professor H. H. Swinnerton kindly allows me to publish his field sketch of one case (Fig. 1a). It will be seen that the laminæ are level and terminate abruptly at the pebble, showing no tendency to heap over it.

Experiment and observation, then, seem to indicate that accumulation of sediment in layers, conformable in shape to a contemporaneous nodule, is unlikely to be frequent. However, such an origin of the structure admits of ready determination, for conformity would be confined to laminæ passing above a concretion—those below necessarily being unaffected. I consider, on the whole, that the characteristic arrangement would be for thin layers to terminate abruptly against a nodule (Fig. 1a), and for those thicker than the nodule to pass in horizontal lines above it (Fig. 1b).

Before considering the remaining possibilities, it may be mentioned that conformity of stratification lines to the shape of a nodule has usually, if not invariably, concomitant phenomena. Such are smooth or slicken-sided contacts; a tendency to the development of cone-in-cone structure in the surrounding matrix; and miniature faulting. These may be fairly attributed to pressure, but whether the pressure is generated by nodular growth or vertical loading has not been established.

These two cases were tested experimentally in the way indicated below:—

(a) A cake of hard soap was embedded in a matrix, formed by superposed layers of different coloured plasticene. These were arranged so that they were thinner than the cake, and terminated, without initial bending, abruptly at its surface. The model was subjected to vertical pressure in a hydraulic machine. When removed from the press and sectioned vertically, the laminæ were found to be compressed over the nodule, thinning out above and below, and generally conformable to the shape of the cake. The removal of the cake showed that smoothing of the contact had taken place (Fig. 1c).

Therefore, pressure applied vertically to a contemporaneous nodule would be competent to cause bending of stratification lines.

(b) The attempt to imitate a nodule "growing" in a deposit presented difficulties. Finally it was decided to force a steel ball gradually into a layer of coloured plasticene. Suitable arrangements were made to prevent plasticene from squeezing up around the ball, as the latter was forced very slowly into the model. Since the ball thus entered at a point, and the volume of the intrusion increased

¹ Swinnerton, *Proc. Geol. Assoc.*, vol. xxix, 1918, p. 20.

with the penetration, the action may be considered as a reasonable imitation of the mechanical conditions that prevail as a nodule grows gradually into laminated stratum.

The lamination planes were seen when the model was sectioned to be bent conformably to the shape of the ball (Fig. 1d). Therefore, a concretion exerting pressure on a medium by gradually forcing itself outwards during growth is also competent to produce conformity of stratification lines to its own shape.

Now, comparing these two cases from the mechanical standpoint, they are related inasmuch as the generating force of the one is the reaction in the other. The general tendency will be to compress layers of the matrix above and below, causing a sideways flow of material into interspaces between the nodules. The net result in both cases is bending of the layers, with vertical thinning and the simultaneous production of subsidiary pressure effects.

It is now essential to determine any features that may be used to distinguish between the two cases. The foregoing discussion has already made it probable that with contemporaneous origin of the concretion the layers will probably settle to a gravitational surface around the nodule. If these layers are thin compared with the nodule, they may be expected to terminate abruptly against its sides, and under the influence of pressure, as in the model, will wedge upwards against the side of the nodule, after the manner of "catenary" bedding (Fig. 1c). If, on the other hand, the deposit is thicker bedded it is difficult to see how the question of relative age could be determined from the phenomenon itself. It may be remarked that if consolidation pressure produced this effect, one might expect it to be at least as frequent over undoubted contemporaneous objects, such as fossils, as it is over nodules. But it certainly is not. Indeed, I have sought long for something of this kind in the field (and I am indebted to many others who have also kept watch in their field work for the same evidence), but hitherto without success. Moreover, there does not appear to be a recorded case. This is on the whole rather unexpected, and I am gradually coming to the opinion that conformity of stratification lines is caused in every case by concretionary growth, and that the date of formation is at the earliest later than the first compacting of the matrix.

III. REPLACEMENT.

Replacement of fossils, of the grain and structural features of the original rock has always been regarded as undoubted evidence of secondary origin. An excellent application of the study of progressive replacement to the problem of relative age may be found in Miss Raisin's ¹ investigation of the Portland Cherts.

W. A. Tarr,² however, has suggested a different explanation of

¹ Raisin, *Proc. Geol. Assoc.*, vol. xviii, 1903, p. 75.

² Tarr, *Amer. Journ. Sci.*, vol. xlv, 1917, p. 428.

fossiliferous chert. On his hypothesis of chert formation, nodules originally existed as globular segregations of silica jelly on the sea-floor. The fossiliferous character of the cherts is explained as due to the infalling of animal remains, which accumulated in these silica balls in the same way as in the surrounding rock.

This hypothesis presents mechanical difficulties. A few experiments with any gel, even though it may contain a large amount of water, will suffice to show that, as soon as a gel has sufficiently coagulated to stand under its own weight, it offers considerable resistance to surface penetration. Heavy objects may be left indefinitely on its surface, and penetrate no further than a small initial indentation.

Large heavy shells possess considerable surface, and this would prevent their penetration into the gel. With regard to minute forms, such as the tests of foraminifera, it is impossible to conceive how *they* could have penetrated the gel. They must also arrange themselves in the same way as they are to be found in the surrounding rock. Yet the viscosity of the gel, even though one granted the possibility of penetration, would exercise a considerable effect on the arrangement of the contents.

From such considerations it would seem that our faith in the old argument of replacement is not considerably weakened by this ingenious suggestion.

IV. MODERN OCCURRENCE.

The occurrence, or non-occurrence, of a particular type of segregation in modern seas has often been employed as a subordinate criterion of relative age. It is, of course, an argument based on comparison. Certain types of concretion, e.g. manganese nodules and phosphatic segregations, *are* found. It, therefore, seems reasonable to expect careful search to reveal something of other concretions that are as abundant or more abundant in rocks of various geological ages.

The argument has been frequently opposed. Sometimes on the ground that the specific gravity of the segregation would carry it deep into the deposits of the ocean-floor beyond reach. However, the list of the materials dredged in the numerous expeditions disposes of specific gravity as the cause of non-discovery. The list includes manganese and phosphate nodules; barytes, terrestrial rocks, including detrital flints, heavy animal remains, debris dropped by steamers, and meteoric granules.¹

A more serious and less answerable objection lies in the possibility that physical conditions necessary for formation of the concretion in question do not pertain in the present ocean. The argument is, therefore, quite secondary, and must be used with due caution. It obtains weight only when a considerable body of other evidence points the same way.

¹ Murray & Hjort, *The Depths of the Ocean*, London, 1912, chap. iv.

V. THE SHAPE OF CONCRETIONS.

H. C. Sorby¹ considered that the shape of nodules depended on that of their nuclei, and gave a series of measurements to demonstrate the point. In some cases this dependence is doubtless a fact, but a broad survey of concretions does not warrant a general application of the principle. Some examples will be given in the following paragraphs to illustrate the subject.

L. Moisey² examined several thousand ironstone nodules from the Notts-Derby coalfield. These nodules, containing fossils flattened vertically, are, on the whole, small, and ellipsoidal in shape. The length and depth of the nodules corresponds fairly well with the length and depth of included fossils, but their width seems independent of that of the fossil. Moreover, some 35 per cent of the nodules examined contained no fossil, yet were similar in shape to those that did.

I have gone over the tip-heaps and exposures afforded by quarries in the Lower Lias of Lincolnshire to collect evidence of the influence of inclusions in nodules. A few of these Liassic doggers (often septarian) may have a large ammonite at their centre. In the majority either no fossils were found, or the fossils were distributed sporadically through the nodules. The general shape of these nodules was also a flattened ellipsoid.

A colleague, Mr. H. S. Holden, recently brought me a small concretion in Coal-measure shale from Gedling. The concretion formed in the neighbourhood of a *Carbonicola*, and its final stages of deposition just embraced the tip of the shell. This small concretion was almost spherical, and the shell had evidently no influence on the origin or location of the segregation. The lamination planes were disturbed by the concretion, but not by the fossil, thus indicating a secondary origin.

Chalk flints occasionally show in their shape the influence of their contents. The majority are, however, highly irregular. This irregularity might be due to local differences in the Chalk, that enabled replacement to take place more easily in certain directions than in others.

Most concretions that have been dredged from the ocean appear to form around some object. And if they are comparable in size with the nucleus, their shape seems to be strongly influenced by it.

Liesegang³ emphasized the general tendency of concretions to assume a globular form. He demonstrated partly by experiment and partly by field observations, that if the segregation be forced initially to depart from the circular form by commencing at an irregular centre, the concretion tends to approximate more and more to that shape as growth progresses.

¹ Sorby, *Quart. Journ. Geol. Soc.*, vol. lxiv, 1908, p. 216.

² Moisey, *GEOL. MAG.*, Dec. V, Vol. V, 1908, p. 222.

³ Liesegang, *Geologische Diffusionen*, Dresden and Leipzig, 1913, chap. vi.

Large numbers of concretions—in fact one may safely say the greater number of concretions—tend to have a shape that may be described as an ellipsoid flattened vertically. This shape may appear indifferently, whether there are central fossils or not. The form suggests a possible analogy with the ellipse of stress, or the ellipse of optic elasticity. If an isotropic substance is compressed in one direction the ease of vibration of a ray in that direction is reduced, and, as for uniaxial crystals, the distribution of vibration ease can now be represented by an ellipsoid of rotation.

It seems reasonable to suppose that concretionary growth should be similarly influenced by the state of stress of the medium. In a homogeneous and unstressed matrix growth should proceed at equal rates in all directions, and, therefore, in a given time reach a spherical boundary. On the other hand, a concretion forming subsequently to the deposition of a rock, and located at some distance from the surface, encounters considerable resistance to growth in a vertical direction. The rate of increase in this direction should, therefore, be less than it is horizontally, and the flattened ellipsoidal shape that prevails in many concretions would be explained.

This phenomenon can be demonstrated by carrying out Liesegang's experiment in a gel subject to greater compression in one direction than in another. It is rather difficult to be sure of getting an unequally stressed gel, but the method described below was successful.

Pour a bichromate gel into a cardboard tray to a depth of about $\frac{1}{8}$ in. Support a glass, or xylonite plate, provided with a small central hole, in contact with the surface of the gel until the latter has completely set. The transparent plate must fit the tray *exactly*. When setting is complete, cut away two opposite sides of the tray, supporting the other pair by wooden blocks. Press the plate on to the surface of the gel and apply weights. The gel is now free to move in one direction, but hindered in the other. It is, therefore, compressed against the remaining sides of the tray. Now place a drop of strong silver nitrate over the central hole, and leave in a damp atmosphere to diffuse.

In all experiments where differential straining of the gel was successful the diffusing silver nitrate reached an elliptical boundary. The shape obtained in two experiments, with the dimensions of the axes, is given in Fig. 2.

It should be mentioned that J. Geikie¹ considered that the horizontal extension of a concretion is due to the greater ease of diffusion provided by lamination planes. This would no doubt assist the phenomenon, but cannot be considered as a major cause, since precisely similar ellipsoids are found in more massive beds, and not located along bedding planes.

¹ Geikie, *Structural and Field Geology*, Edinburgh, 1912, p. 121.

It will, therefore, be seen that contemporaneous concretions would be favourably placed for the development of spherical form. Examples of such are manganese nodules and "marlekor". The latter are aggregations of spheres and have been imitated in unstressed gels by Liesegang.¹ The spherical shape may also be attained by concretions of subsequent age, providing there is a homogeneous environment. On the other hand, the flattened ellipsoidal shape seems confined to displacive, or partially displacive subsequent nodules. Replacements are capable of very irregular development as many economic deposits show.

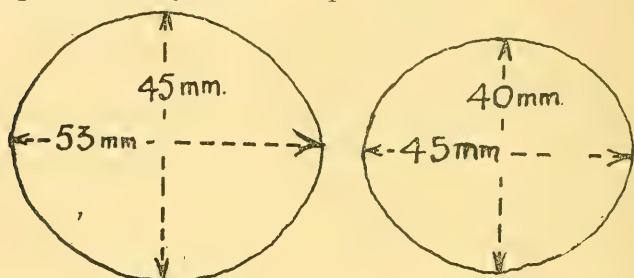


FIG. 2.—Shape and dimensions of two boundaries reached by silver nitrate diffusing in an unequally stressed gel.

VI. THE DISTRIBUTION OF NODULES.

The following modes of distribution may be distinguished :—

1. Sporadic distribution appears to be characteristic of most concretions to be found on the ocean-floor or in recent alluvial deposits.

2. The majority of phosphatic nodules are located at a definite level. The nodules themselves are frequently rolled, bored by molluscs, and carry attached contemporaneous animal remains. They are contemporaneous and have been formed where there is a pause in sedimentation.

It may be remarked in this connexion that so far as the evidence goes, modern concretions seem to form very slowly. It follows that they must occur where sedimentation is also slow.

3. Some nodules occur in definite lines, parallel to the bedding. The spacing of the lines follows apparently some law or "rhythm", sometimes in a very marked way. Moreover, several observers have called attention to a tendency for the distance between the individual nodules of a given bed to be uniform. Failures to find competent external causes of this arrangement have led to the suggestion that the rhythmic precipitation of diffusing solutions is the cause. In some cases there is a strong resemblance to the sequence of Liesegang banding. For example, closely spaced bands may be followed by a region where the bands are progressively more

¹ Liesegang, loc. cit., chap. xviii.

widely spaced, as indicated in Fig. 3a. The close regular banding may be both followed and preceded by such regions (Fig. 3b). Widening of the spacing is often accompanied by a reduction in the average size and number of nodules, and by the tendency for the banding to give way to "scattered zones".

The whole series may represent a single rhythm. There is, then, a presumptive case that all the concretions were formed by one process of precipitation. As diffusion continued the concretionary layers were deposited progressively—the whole process extending over a period, as to the duration of which nothing is known.

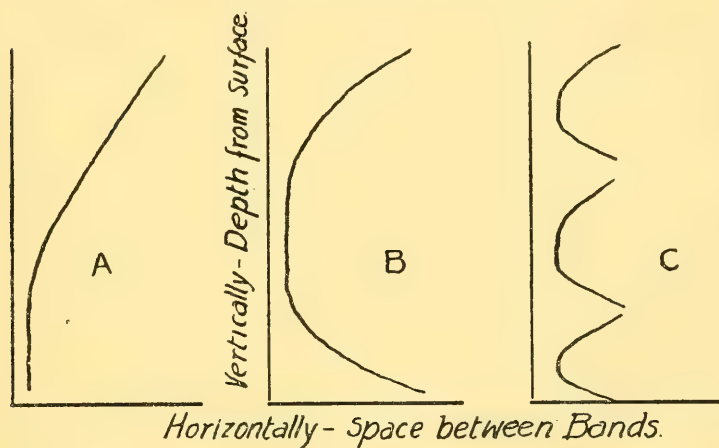


FIG. 3.—A, Liesegang rhythm. B, Another type of Liesegang rhythm. C, Three Liesegang rhythms in one deposit.

On the other hand, it may sometimes be possible to divide up the layers of a given deposit into sets, each showing the characteristics of a single rhythm. The case is presented diagrammatically in Fig. 3c.

If only a single rhythm can be detected it may be taken that the concretions are the result of a single process spread over a time-interval commencing at the earliest after the complete deposition of the rock.

The detection of two or more such rhythms in a single series indicates that after the overburden of sediment had reached a certain thickness precipitation and concretionary growth took place. Such may be the conditions under which concretionary liassic limestones were deposited according to the hypothesis of W. D. Lang.¹ This hypothesis has recently been further investigated by E. F. Davis,² and called by him "colloidal segregation".

¹ Lang, *Proc. Geol. Assoc.*, vol. xxvi, 1915, p. 117.

² Davis, *Bull. Dept. Geol. California Univ.*, vol. LL, vol. II, vol. 11, No. 3, 1918, p. 394.

VII. SUMMARY.

The following features are favourable to contemporaneous age :—

1. Spherical form.
2. Sporadic distribution or occurrence at a pause in sedimentation.
3. Gravitational bedding around the nodule.
4. Modern occurrence.

The following features are favourable to the subsequent relative age :—

1. Replacement of the fossils, grain, and structural features of the parent rock.
2. Displacement of the stratification lines, above and below the nodule, conformably to its shape.
3. The development of a vertically flattened form.
4. The arrangement of the nodules in lines showing a marked rhythm.

It should be hardly necessary to remark that no one of these features can be decisive. The whole of available evidence must be taken into account, and considered with any special local evidence that may be available. Thus, G. W. Lamplugh's¹ observation that a band of crushed ammonites passes through the nodules puts the date of the concretion as later than the crushing. The subject is difficult and agreement is far from being reached, although the matter has received the attention of generations of able geologists.

I should like to express my thanks to Professor H. H. Swinnerton, D.Sc., and to Messrs H. S. Holden, M.Sc., and H. C. Sargent, F.G.S., for discussing various aspects of this work with me.

On the Geological Features of the Oil Region in the Northern Punjab (British India).

By H. PREISWERK, Basle.

(Concluded from p. 80.)

Occurrence of the Oil.—The oilfield of Jaba and those of Rawalpindi and Fatehjang are identical from the stratigraphical point of view. At Jaba, too, the oil is to be found in the contact zone between the Nummulitic limestone and the younger gypsiferous clays of the Upper Nummulitic. These gypsiferous clays represent a bed well adapted to favour the accumulation of oil, wherever they cover the limestone at a moderate inclination. The oil issues only from the limestone, but the cellular limestone, too, may be oil-bearing in depth. It may be pointed out that cellular limestones of the same character accompany the oil-shows at Gunda, the main oil-spring in the neighbourhood of Fatehjang.

At Chota Kutta and Burra Kutta the oil flows out mixed with

¹ Lamplugh, *Quart. Journ. Geol. Soc.*, vol. xiv, 1889, p. 582.

sulphur water, but in the boring at Chota Kutta the oil is free from water as far as I know.

Near the oil-springs the beds have steep inclinations, especially at Burra Kutta. In order to find more favourable places for borings we have to discover localities where the roof of Nummulitic limestone lies under the ground and almost flat. My geological researches in this part of the Salt Range show that such places probably exist. First we may suppose that the oil-bearing beds take on in depth a flatter dip, as the overlying sandstone beds show a lower dip to the north-east only a short distance from the range.

Of importance are also those places where the axis of an anticline pitches to such a degree that the core of the fold, which is formed by Nummulitic limestone, is covered by the Upper Nummulitic and the Murree beds. Such places are found south of Burra Kutta, where the anticline A dips below, and at the entrance of the ravine of the Majukh river, where the anticline B comes to an end on the surface.

Extension of the Oil-bearing Beds in the Salt Range.—It is quite probable that the occurrence of oil is not limited to the immediate neighbourhood of the oil-springs, but has a larger extension to the north-west and south-east along the border of the range. The geological features of this border ought to be studied more completely. Several occurrences of tar south-east of Jaba are indications of the extension of the oil-bearing beds over a large part of the western Salt Range.

At Kallar Kahar I have obtained a sample of tar which was brought by a native from the outcrop 2 miles north of Khabakki in the Shahpur District. According to A. B. Wynne's excellent geological map, these outcrops are situated near the upper limit of the Nummulitic limestone, that is to say, on the oil-horizon. Accordingly the tar occurrence at Khabakki acquires some importance as an indication of the extension of oil rocks in the western Salt Range. B. S. Lyman mentions in his report several tar-occurrences in this district: "The Chinnoor rock tar near Murdowal (Shahpur District), and 83 miles south-west of Pindi; the Hungooch rock tar near Dhuddo and Murkoom (Shahpur District), and 81 miles south-west by south of Pindi; and the Doona rock tar near Kubbukkee (Shahpur District), and 77 miles south-west by south of Pindi." There is no doubt that Lyman's "Kubbukkee" and the "Khabakki" of the topographical map (scale 1 inch = 1 mile) are the same. The names "Murdowal", "Dhuddo", and "Murkoom" are probably to be identified with the names "Mardwal", "Dadhar", and "Mukrumi" of the topographical map (No. 43 D 2). Mardwal is situated 5 miles, Dadhar and Mukrumi 3 miles west of Khabakki. These distances might be brought in accordance with those given by Lyman.

Evidently we have to deal here with several tar outcrops, running with the strike of the strata for many miles, a fact which is worthy of consideration.

In the eastern Salt Range, however, as before shown, we find quite another petrographic character of the Upper Nummulitic. Near Kallar Kahar the coarse oolites—the same as those that form the roof of the oil-beds in Jaba—are also developed, but they lie directly on the massive Nummulitic limestone. The cellular limestones and the gypsum marls are missing. Farther east the Upper Nummulitic, developed as yellow brittle marls and calcareous nummulitic beds, is only about a metre thick. There are no oil-traces to be found in the whole eastern Salt Range in this horizon.

C. THE BURNING GASES OF JAWALAMUKHI, DISTRICT KANGRA.

Jawalamukhi may be reached from the railway stations Hoshiarpur or Pathankot. A new and well-made road, suitable for tongas, leads from Pathankot to Kangra (53 miles). From Kangra another road leads to Jawalamukhi (23 miles); this can be used, however, by ekkas only.

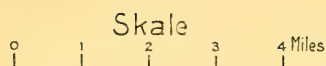
In the temple, which is often visited by Hindus, inflammable gases rise from the ground. In the chief room of the temple visitors are shown several feebly luminous, bluish flames bursting out of a hollow. In another part of the temple, lying a little higher, about 10 metres distant from the former, the gas comes out of a water reservoir, and is brought to explosion from time to time. The colours of the flames lead one to think that the gases chiefly consist of methane.

H. B. Medlicott (Mem. Geol. Surv. India, vol. iii, 1864, p. 146) mentions this occurrence in the following words: "At the famous shrine of Jawalamukhi an inflammable gas perpetually issues from the rock (unless, indeed, it be cooked by the priests below ground)". My examinations in the field, however, proved remarkable relations between the geological features on the one hand and the occurrence of the gases on the other, so that Medlicott's suspicions may be without foundation.

In the brook behind the fire-temple there is a bluish-gray sandstone bed about 15 metres thick, covered by red marls dipping north-east at somewhat more than 40°. On the right side of the brook the red marls and the sandstone bed lie about 20 metres lower. They have sunk along a small transverse fault running north-east. Above the sandstone bed there follow with frequent alternations sandstones with fossil plants and red marls with calcareous concretions. Similar rocks form the whole steep slope (over 1,000 feet high) to the east of the village. The marly layers, however, decrease a little towards the top, sandstones predominating.

Towards the top the dip of the beds decreases continually. On the crest of the mountain they dip only at 25° north-east and farther east 15° and less.

According to Medlicott this series and all the other rocks of the environs of Jawalamukhi belong to the Siwalik formation.



- Anticlinal
- - - Synclinal
- I. - IV. Sections of fig. 15
- ↘ Strike and Dip
- † The Golden Fire-Temple at Jwalamukhi
- Saltwater-Springs

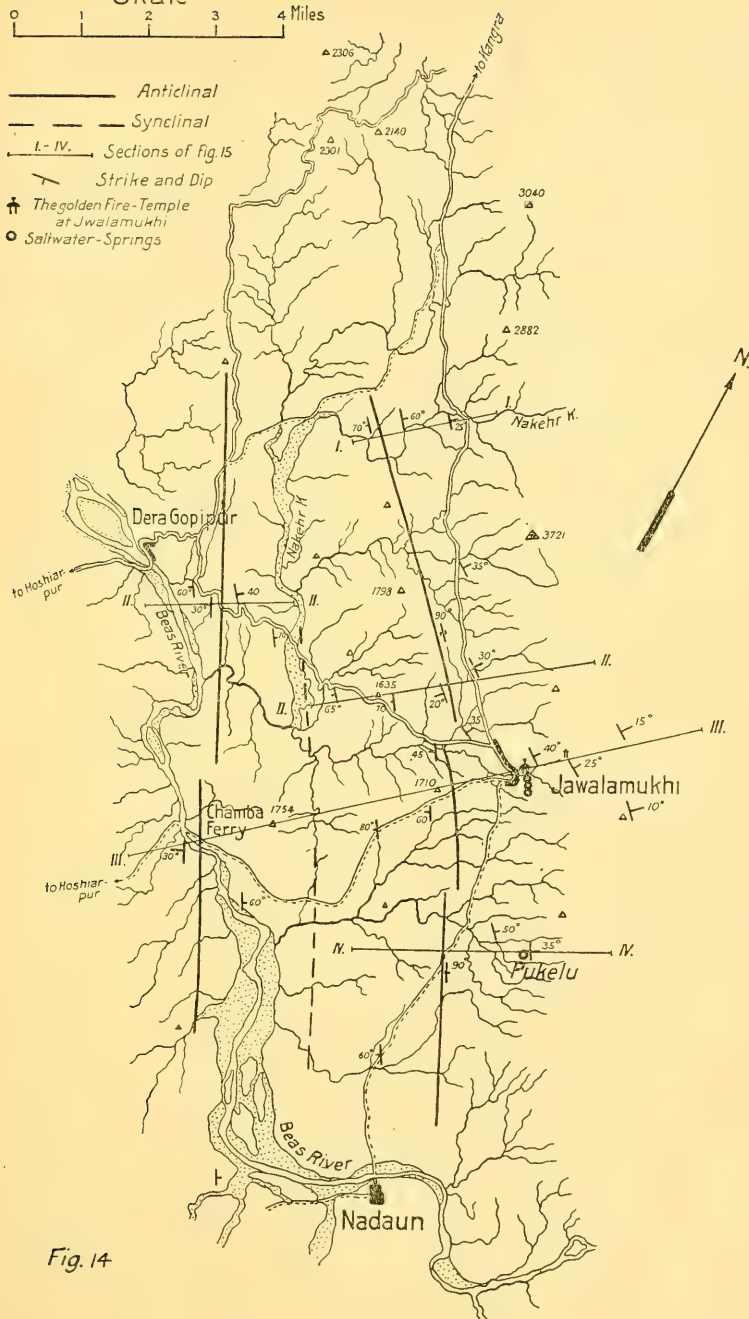


Fig. 14

The Siwalik formation consists here of tremendously thick sandstones, clays, and conglomerates in frequent alternation. In the Upper Siwalik conglomerates decidedly predominate, in the lower one clays. No well-marked leading horizons have so far been found in this mass.¹

These Siwalik beds form, in the region I have examined, two enormous anticlines running through the country in a fairly straight line for many miles, even one day's journey in a north-west-south-east direction. They were recognized even by Medlicott as important tectonic lines. He called them after places lying further south—"Gumber fault" and "Budsar fault". The eastern "Gumber fault" will in this paper be called "Jawalamukhi anticline", the western "Chamba Ferry anticline". Chamba Ferry is a point on the Beas River, where the anticline is very clearly exposed. The details in the course and in the shape of the anticlines are represented in Figs. 14 and 15. The geological observations which led to the construction of the anticlines are entered on the map (Fig. 14). I have to draw special attention to some points.

The axis of the Jawalamukhi anticline does not coincide with the steep mountain range, the "Jawalamukhi ridge", at the foot of which the fire-temple is situated, but lies generally at one mile distance from the mountain border.

While vertical bedding appears in the axis in several places, the anticline shows just at Jawalamukhi a fine regularly curved structure.

Towards the north the anticline is curved off a little to the north-west. Transverse faults result from this. The fold is built unsymmetrically with a steep south-west flank and a flat north-east flank. The anticlinal crest must, therefore, under ground remove itself a little to the north-east. To the north of Jawalamukhi the axis of the anticline pitches considerably to the north-west. In the syncline between the two anticlines conglomerates, that is to say, the beds of the Upper Siwalik group, predominate, with very steep dips.

The core of the syncline lies closer to the Chamba Ferry anticline than to the Jawalamukhi anticline. Therefore, supposing similar facies, the Jawalamukhi anticline is curved up more strongly and shows deeper beds than the other one.

The appearance of burning gases (methane gases) is often, but not always, in connexion with oil-rocks. In districts, where oil exists, the appearance of inflammable gases, together with salt-water springs, is considered a reliable indication for oil.

Both gases and salt water are found in Jawalamukhi. Opposite the fire-temple on the southern side of the brook salt-springs come forth below the road. Several further salt-springs are found a little south in the steep slopes east of the village of Jawalamukhi. I also

¹ Medlicott, *Manual of the Geology of India*, 1879, pp. 550-4.

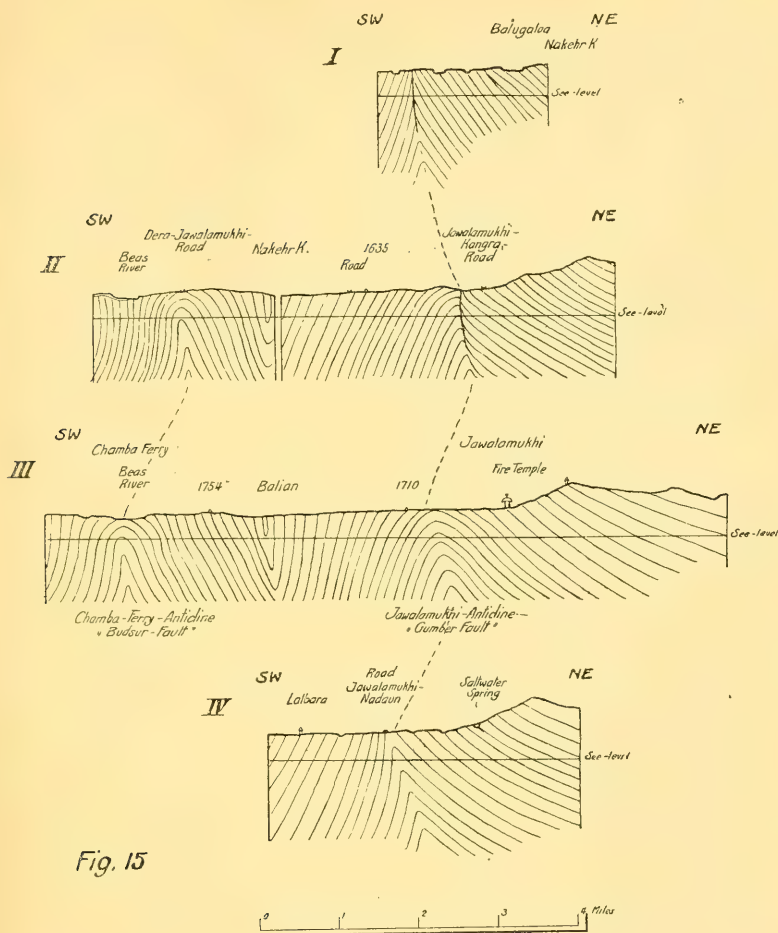


Fig. 15

examined another salt-spring lying wholly isolated from those mentioned just now near Pukelu (or Focolo) about one hour south-east of Jawalamukhi. Two salt-springs have their origin there on the slope of the hills at a height of 80-100 mm. above the plain. They come from practically the same stratigraphical level as the salt-springs and the gases of Jawalamukhi, at exactly the same distance from the antilinal axis.

There is no doubt of these gases having a geological connexion with the salt-springs. Both probably are in connexion with a salt-mass in depth. Such a salt-mass is, indeed, known. It appears at the base of the Tertiary formation in the mountains about 30 miles

east of Jawalamukhi, where the so-called "black salt" is won at Gama and Drang near Mandi (cf. *Medlicott, Mem. Geol. Surv. India*, vol. iii, p. 60).

Gas and salt water probably have found their way from depth on transverse fractures, and small transverse faults can be proved here and there (Fig. 14).

"Lissons."

By L. RICHARDSON.

IN the Oolitic rocks of the Cotteswold Hills fissures are of frequent occurrence. Noticeable phenomena are that when snow or hoar frost is on the ground it is usually melted or not deposited along the lines of these fissures and that air is usually continuously expelled from them.

In the neighbourhood of Stroud these fissures through which air is expelled are known as "Lissons". Air is also expelled from other openings in the Oolites—for example, from deep wells. Mr. Charles Upton informs me that from a well 175 feet deep down to the water, at Bownham Cottage on Rodborough Hill, Stroud, the air was always blowing strongly both winter and summer—so strongly, indeed, that a lighted candle was immediately extinguished. People who live on the Cotteswolds are frequently heard to remark that their house is built on "hot rock", meaning thereby that there is a "lisson" or fissure under the house. The effect of this on the house is that it is always damp, and the floors rot and decay in a comparatively short time. There are many houses so situated in Rodborough.

In Mr. Upton's opinion the fissures act as vents for the air which is pressed by barometric pressure into the ground over its whole surface, more readily, obviously, where the rocks are of a more or less porous character, as in the case of the Oolites. The pressure is, of course, continuous, and so also is the outflow, but its effects are only visible in the winter time, when, as remarked above, the snow or hoar frost is either melted or not deposited at all along their line.

The effects of the pressure of a strong wind is often noticeable in wells in the hills. Thus I have been informed that the water in the well that supplies Coates, near Cirencester, usually stands at a higher level when a strong wind is blowing.

REVIEWS.

THE GEOLOGY OF PONDOLAND. By A. L. DU TOIT, D.Sc. Expl. Cape Sheet 28. Geological Survey of the Union of South Africa. pp. 44.

THIS unassuming little memoir of only forty-four pages and the accompanying map contain the record of a piece of work of really remarkable character when we take into account the nature of the country. It comprises a description of the geology of Pondoland and portions of Alfred and Lower Umzimkulu Counties, Natal. This is a region of high plateaus, deeply dissected by river gorges, often with vertical sides; in parts covered by dense forests and only sparsely settled; much of it is native reserve and very little known. Nevertheless, Dr. Du Toit has worked out the geology in much detail, and has discovered many interesting features. The geological formations represented are as follows: oldest of all are the crystalline dolomites of the Marble Delta on the Umzimkulu River, in Natal; then come granites, usually gneissose, and amphibolites of pre-Cape age. The Cape system is represented only by the Table Mountain sandstone, the upper part being absent. The Karroo series is apparently quite complete and very thick. Above this come Lower Cretaceous sandstones and conglomerates, the Embotyi beds, followed by the well-known fossiliferous marine Upper Cretaceous, generally known as the Umtamvuna series. The author says these beds do not occur at the locality from which the name is taken, and he renames them the Umzamba beds. No Tertiary strata have been found. The correlation of the sandstones of Natal with the Table Mountain series, for long in dispute, may now be considered as established. This formation is in many ways remarkably like the Millstone Grit. The Dwyka conglomerate is well developed, and it is considered that in southern Natal its thickness may be as much as 1,500 feet.

The tectonics of the country are very fully discussed, and the existence of some very important dislocations is established, such as the great Umgazana and Egosa faults. However, in spite of the numerous items of interest that might be mentioned, we can only afford space to refer to one special problem, namely, the general nature of the structure determining the coast-line of this area. It is here shown that the view upheld by Suess, among other geologists, that the coast-line is a great fracture, is untenable. The present work confirms Penck's idea that the principal factor was a monoclinal flexure extending along the Lebombo range and then striking S.S.W. through Zululand and along the coast of Natal. Its axis just clears the shore of Northern Pondoland, but is brought inland again by transverse faulting; it must, however, again run out to sea further south. The age of this flexure is not certainly fixed: it is post-Stormberg (i.e. post-Liassic), but its relation to the Cretaceous strata is unknown. Another feature of interest here described is the terrace of marine denudation traceable for a long distance at 1,000 feet above sea-level; other similar shore-lines are traceable up to 2,000 feet, but the latest movement was one of

depression, as shown by the depth to the rock-floor of some of the river mouths.

R. H. R.

THE EVOLUTION OF A COAST-LINE, BARROW TO ABERYSTWYTH AND THE ISLE OF MAN, WITH NOTES ON LOST TOWNS, SUBMARINE DISCOVERIES, ETC. By WILLIAM ASHTON. pp. i-xiv and 1-302. London: Edward Stanford. 1920.

THE author has long been engaged in the study of the features presented by the coast-lines considered in this volume, which is based upon his former work *The Battle of Land and Sea*.

There is, especially in the earlier chapters, a good deal of geological matter which is hardly relevant interspersed with information of considerable interest. If the story had been written in a more connected form it would have saved the reader much trouble. Notwithstanding these objections, the book will be found of very high value to anyone concerned with the study of the coastal changes in the area described, for it is a storehouse of facts, many of which are derived from a study of historic documents, including old maps, while others are due to the author's personal observations.

The author maintains that for some thousands of years subsidence has been in progress along the Welsh, Cheshire, and Lancashire coasts to a point provisionally fixed somewhere between Fleetwood and Barrow-in-Furness, north of which elevation is proceeding.

The volume is amply illustrated with diagrams, maps, and photographs, including a large number of ancient maps of the coastal tract.

J. E. M.

POPULAR OIL GEOLOGY. By Professor VICTOR ZIEGLER. First edition, pp. viii + 149, 1918. Second edition, pp. xii (not numbered) + 171, 1920. New York: John Wiley & Sons, Inc. London: Chapman & Hall, Ltd.

THE word "popular" prefixed to the title of any book purporting to deal with a particular branch of Natural Science is usually sufficient to deter the average technical man from a perusal of its pages. Possibly its use unconsciously reminds us of all the quaintly worded phrases and ambiguous paragraphs characteristic of volumes written with the intent of making a difficult subject easy, and one is inclined, however erroneously, to prejudge and condemn a work bearing this superscription. It is given to comparatively few scientific men to be able to write a technical treatise which, while intelligible to the general public, at the same time satisfies the most critical expert; the author of the present work, being admittedly one of the "few", is therefore to be congratulated on the production of this volume, which fills a very definite space in the literature of oil-field technology.

The book deals only with the general principles of oil geology, and does not attempt to go into elaborate detail. The early chapters are mainly chemical, and discuss the composition, properties, and origin of oil and gas. The succeeding seven chapters are devoted to

the geological aspects of the science, and chapters 7 and 8 (dealing with the reservoirs of oil and gas, and with the laws of migration and accumulation of petroleum respectively) are especially good. In the discussion of maps and their uses (chapter 9) the author is rather bound down by American convention, and he has not treated this phase of the subject as widely as its universal importance merits; in this connexion brevity may very easily lead to ambiguity or inaccuracy, and the dismissal of "structure maps" and "isochore lines" with two short paragraphs is to be deplored. The chapter on oil structures is somewhat fuller and includes a classification of American oil-fields on the basis of varying tectonic features. The fields are classed with reference to folded structures, monoclinal dips (homoclines), dome structures, faults, and unconformities; such a classification is, of course, open to the criticism that in one field two or more structures may occur, as in the case of Wyoming, where all five of the foregoing features are known, but usually one main type of structure predominates and thus justifies the attempt.

The volume also includes some remarks on the kind of surface indications to be looked for in prospecting for oil; in this connexion it is gratifying to note that the author does not follow the usual lines suggested by some writers who advocate drilling a test well wherever two or more likely seeps of oil and gas can be correlated with supposed anticlinal structure. However favourable the surface indications may be, the geological structure must be proved first of all, and the superficial evidence of oil taken at its true value, i.e. as confirmatory evidence. The sentence in the final paragraph of this section might well have been italicized in order to accentuate its importance, since it is a golden rule for all prospectors: "Drilling should be undertaken only on a favourable geological structure in rocks proved petroliferous." Adherence to this policy not only condemns "wild-cattling", but makes for success in oil finding by minimizing risks and eliminating that undesirable factor of "chance".

Although the volume can be read through easily in an hour or so, it contains so much information, concisely arranged and carefully illustrated, that one keeps a copy near to hand for repeated reference where general principles rather than textbook detail are required. We would draw the attention of both author and publisher, however, to the somewhat excessive price charged for a book of this size and description; in its first edition at 11s. 6d., and in its more recent edition at 16s. 6d., the volume may be said to be anything but "popular". That is the most general criticism made since its publication in 1918.

H. B. MILNER.

THE GEOLOGY OF THE LOMAGUNDI MICA DEPOSITS. By H. B. MAUFE. Short Report No. 10, Geological Survey of Southern Rhodesia. pp. 8, with 2 figs. 1920.

THE country rock of the district consists of mica-schists and quartzites, believed to be an unusually highly metamorphosed facies of the Lomagundi system, which is considered to be

generally equivalent to the Transvaal system. The schists are invaded by a granite comparable with the Newer Granites of the Cape Province. The mica occurs in a remarkably regular manner in large "books", usually on the walls of pegmatite dykes, which consist mainly of felspar, with a little quartz, and often with tourmaline and rarely large prisms of beryl. The mica is wholly muscovite, usually either the ruby or bottle-green variety, sometimes clouded and silvery, the books varying from four to five inches in diameter to as many feet, and generally not more than six inches thick. The visible supplies are large and the industry shows much promise.

REPORTS AND PROCEEDINGS.

EDINBURGH GEOLOGICAL SOCIETY.

January 19, 1921.—Mr. D. Balsillie, B.Sc., F.R.S.E., Vice-President, in the Chair.

1. "An Address on 'The Topography of Spitsbergen'." By John Mathieson, F.R.S.G.S.

Mr. Mathieson stated that Spitsbergen was discovered by the Dutch in 1596, while they were attempting to find a North-west Passage. The archipelago consisted of a group of five large islands, with numberless small ones, and the estimated area was 25,000 square miles, or half the size of England. Although within 700 miles of the North Pole and 1,620 miles north of Edinburgh, the summer climate was not much colder than the Shetlands, and the winter was much milder than either Moscow or Winnipeg, a condition which was entirely due to the influence of the North Atlantic drift. The largest island on the west, known as the mainland, was deeply indented with many fiords, the largest, Icefiord, extending over 50 miles. Flanked against the mainland by Prince Charles Foreland—first explored by Dr. W. S. Bruce—which had an area of 250 square miles, with a mountain range rising to nearly 4,000 feet. The general appearance of the country was indicated by the name, which meant "sharp-peaked, rocky mountains", rising generally to a height of 2,500 to 3,500 feet, with one peak in the south over 5,000 feet, and Mount Newton in the north, 5,676 feet. The west was comparatively free from ice, but the north-east of the mainland was covered with a sheet 1,000 feet thick, while the North-east Land was covered with an ice-sheet 1,700 feet thick. Barents and Edge Islands were practically free from ice. Stor Fiord was selected by the Russo-Swedish authorities to measure an arc of meridian (1898–1902) which extended from South Cape to the Seven Islands, a distance of over 300 miles. Glaciers were receding on the west, but there were still many flowing to the sea, and calving icebergs during the summer. The rate at which these glaciers moved had not been fully examined, but one measured this year showed about

100 feet per annum. A specially interesting feature of the landscape was the raised beaches, which could be traced to over 300 feet above sea-level. For 200 years after its discovery—Spitsbergen was the whale-hunting place of the world, one company alone capturing 32,000 whales in 46 years, and until recent times it was the trapper's hunting ground for reindeer, fox, bear, seal, and walrus. But now that the fauna had been ruthlessly exterminated, there was a rush to exploit the rich coalfields, which occurred in the Tertiary, Jurassic, and Carboniferous periods, and were estimated to contain over seven billion tons. The flora consisted of 140 or so of Arctic flowering plants, lichens, and mosses, affording ample food for reindeer, and during the summer a grazing for cows at mining centres.

2. "An Exhibition of Sketches Illustrating the Scenery of Spitsbergen." By H. M. Cadell, J.P., D.L., B.Sc., F.R.S.E., of Grange, Linlithgow.

Mr. H. M. Cadell exhibited a series of water-colour sketches and panoramas he had drawn during a visit to Spitsbergen last summer, showing the character of the scenery of the Ice Fiord district, in central Spitsbergen, and of the shores of Bell Sound and Lowe Sound, further to the south. The prevailing colour of the mountains was of a dun or brownish tint, and the lower parts of the cliff faces were buried under long scree slopes of crumbling debris. The geological structure was for the most part quite simple, and there were few faults or folded strata over wide areas. The most important line of fault or upthrust skirted the west coast, and produced a more picturesque kind of scenery than that of the undisturbed regions. The Middle Hook, a jagged mountain at the mouth of Lowe Sound, displayed the upturned strata in a magnificent cliff face at Axel's Island, which, unlike most other spots, was partly covered with green vegetation that added to the artistic effect of the landscape.

ROYAL SOCIETY OF EDINBURGH.

February 7, 1921.

"Depths and Deposits of the Weddell Sea." By J. M. Wordie, M.A., F.G.S.

A description of some of the oceanographical work of the Shackleton Antarctic Expedition, 1914–17. "Blue mud" is no longer considered a suitable term for the deep-sea deposits off Antarctica; "glacial mud and clay" more fitly expresses the poorness in organic remains and the lack of any sorting out of the constituents according to size characteristic of other glacial deposits. Rock fragments were frequently got whilst sounding or dredging; and from a study of the prevailing drift in the Weddell Sea it was clear that they must have had their source in Coats Land. They offer the only evidence of its geological constitution, and suggest affinities with Victoria Land rather than with Graham Land.

The soundings made almost every day led to the discovery of an unexpected shallow area in the south-west. The continental shelf here has a breadth of at least 100 miles, and was followed over a distance of 300 miles. The depths clustered either about 180–190 fathoms or 250–260 fathoms; the back and forward drift of the *Endurance* showed that the structure of the sea bottom there was a series of stepped plateaus. The abnormal depth of the continental shelf round Antarctica is probably due to earth movements. The position of the isobaths for 1,000, 1,500, and 2,000 fathoms, and the drift of the ice practically settled the vexed question of “Morrell’s land”, whose existence must now be considered highly improbable.

MINERALOGICAL SOCIETY.

January 18.—Mr. A. Hutchinson, Vice-President, in the Chair.

A. F. Hallimond : The Olivine Group.

Since the discussion of the densities by Thaddeef in 1896, and of the optical constants by Backlund in 1909, numerous additions have been made to the published data. These have been collected, and the most probable values for the pure compounds obtained. The molecular volume of monticellite is slightly greater than the mean between forsterite and $\gamma\text{-Ca}_2\text{SiO}_4$. For the complex mixtures the density and mean refractive index yield additive relationships, but the birefringence and axial ratios follow no additive law. The conditions of plotting which must be observed if the variation of an additive property with composition is to be expressed by a straight line were briefly summarized.

W. A. Richardson : A Method of Rock-analysis Diagrams based on Statistics.

Oxide variation diagrams, similar to those employed by Dr. Harker, can be used for expressing the chemical relations of rock groups and individuals. The diagrams obtained from plotting Iddings’ selected analyses gave the maximum variation for all rocks.

L. J. Spencer : Identity of Trechmann’s “ β -tin” with stannous sulphide.

A re-examination of the original material described by C. O. Trechmann in 1879 as an orthorhombic modification of tin proved that he made his crystallographic determinations on crystals of one kind (viz. stannous sulphide), whilst the chemical analysis was made on crystals of another kind (viz. metallic tin). Tin, is therefore dimorphous and not trimorphous, “white tin” being tetragonal and “grey tin” cubic. Orthorhombic crystals of stannous sulphide (SnS) and tetragonal crystals of iron stannide (FeSn_3) from tin furnaces, and rhombohedral crystals of tin arsenide (Sn_3As_2) isolated from a tin-arsenic alloy were also described.

CORRESPONDENCE.

THE GLACIATION OF IRELAND.

SIR,—Professor Kendall's criticisms of my paper on Irish Eskers include various specific objections.

(1) He complains of lack of deliberation. The first of my many visits to Irish eskers was in 1887. At my time of life I cannot hope for equal further deliberation.

(2) He objects that the paper contains very few new field observations. I should have been less surprised by the complaint that the paper quoted too lengthily from my field note-books; seventeen pages out of thirty-five are occupied by detailed descriptions of representative eskers and mainly of their internal structures; and I justified this length on the ground that the previous literature "deals mainly with their distribution and general structure" (p. 116), and but little with their intimate structure.

(3) Apparently I should have quoted my notes at still greater length, for compression has led to misunderstanding. In accordance with Professor Kendall's habit of regarding as simple mistakes views he does not accept, he so dismisses the attribution of the crescentic series of eskers around the northern end of the Slieve Bloom Mountains to ice from those hills. He says I "might have been spared this mistake" had I consulted G.S.I. Memoir, No. 117-8. I had not only consulted it but quoted it, for its account of some "anastomosing eskers". Professor Kendall's quotation from that Memoir supports my conclusion; for the rarity of Galway granite on the northern in contrast to its abundance on the southern slopes of the Slieve Bloom Mountains, is most easily explained by its entrance having been hindered or by it having been subsequently swept away by local ice. The existence of this local drift is recognized in the Memoir, No. 127, p. 26.

As regards the position of Roscrea, my sentence: "The Roscrea, Clonaslee, Mountmellick, and Maryboro Eskers were probably formed by ice which flowed down the northern slopes of the Slieve Bloom Mountains"—was an attempt to indicate in two lines the relations of over 30 miles of esker. They are part of one crescentic series around the northern end of the range. Moreover, the term Slieve Bloom Mountains is sometimes used (e.g. Phillips, *Atlas of Comparative Geography*, and the map used in Carvill Lewis' *Glac. Geol. Gt. B. and I.*, 1894, opp. p. 83), to include the geological continuation of the range south-west of the Roscrea Gap, and in that sense the south-western or Roscrea end of the series is north of the range.

I referred so briefly to this series because unusual detail had been given of its internal structure (e.g. Memoir, No. 126, p. 22).

(4) The origin of the boulders is but exceptionally referred to in my paper because it is so seldom that the last direction of movement can be inferred from the nature of the included rocks. Thus, the granite in the kame near Barony Bridge, Tyrone, gives

no clue to the movement of the ice which made the kame. No doubt the area was invaded by ice from the north-west; but the movement at the time of the kame formation is not shown by the original home of the boulders. According to Professor Cole (*Reg. Geol.*, iii, p. 329, received after my MS. had been sent to the Royal Society) the materials of the Tyrone eskers were distributed from south to north. I am sorry to differ from Dr. Charlesworth regarding an Ulster kame, and if he will publish his evidence I will carefully consider it; but I find it difficult to realize how this kame, steeply descending the hill to the north and with its curves concave to the south-east, can be due to ice from the north-west, although much of its material originally came from that direction.

Professor Kendall claims that by insertion on Fig. 9 of two arrows from Professor Sollas's map I have unintentionally contradicted the statements in the text that the ice flowed in the opposite direction. I described the Dunmore eskers in reference to the claim that they were deposited within ice which was moving at right angles to their trend. For, if so, and if glaciers have any power of erosion, it would appear clear that the eskers must have been formed after the ice had ceased to flow across their sites. I agree with Professor Sollas that the course of the ice was along a line trending north-west and south-east; and to show that Professor Sollas adopted that course I inserted the two arrows from his map. The legend of the figure quotes them as from Professor Sollas, and as marking "the course of the ice movement", not its direction along that course. It is made clear in the text that I consider that the direction adopted should be reversed; but I left the arrows to prevent any possible suspicion that I was claiming Professor Sollas's agreement with the direction of movement as well as with its course. Whether the ice moved from or towards the north-west being immaterial to the formation of these kames, I mentioned my conclusion and the nature of the evidence, but did not give it in detail.

(6) Professor Kendall also objects to my insertion on a sketch map (Fig. 11), showing the relations of the eskers to the 300 foot contour of some arrows indicating the ice movement according to Mr. W. B. Wright. The first objection raised is that Mr. Wright's map refers to the maximum extension of the ice and not to the stage to which I assign the eskers. But the theory which I was proposing to amend is that the eskers were formed by rivers within the great ice-sheet; and one fact I hoped to show by the figure was that many of the chief eskers trend across the line of the movement of the ice, and were formed on its margin during its retreat, and not within it. To that argument the map is relevant. The second objection is that I have unduly magnified the lines. In order to prevent attaching to Mr. Wright's lines a significance as to details greater than the scale of his map would warrant, I ended the lines to the south against the hill country of Slieve Bloom, between

Lough Derg and South Kildare. I inserted only thirteen out of the thirty-eight lines marked by Mr. Wright, as they were sufficient to show the general view as to the ice-movement in Mid-West Ireland. Eleven out of the thirteen lines follow the originals precisely; the two easternmost are rather generalized to show the movement east of Lough Ree and trend rather farther to the west than the nearest corresponding of Mr. Wright's lines; but this difference does not affect the argument, as their direction in the original is athwart the chief eskers, and is inconsistent with the formation of the eskers by intra-glacial rivers.

Origin of Boulder Clay.—Passing to the general question of the origin of boulder clay, Professor Kendall states that I intend "a general assertion of the marine origin of all boulder clay". No such assertion is intended. I briefly stated my view of its origin in *Geology of To-day* (p. 227). So far from claiming all boulder clay as marine, I described its formation in an ice-blocked depression at the head of the Fulmar Valley in Spitsbergen. It is, however, sometimes subaqueous, deposited either in lakes or in quiet arms of the sea as off the Sefstrom Glacier. Each case must be determined by the local evidence, and where the boulder clay contains contemporary foraminifera, the possibility of its origin as marine mud must be considered. The foraminifera cannot be simply dismissed as derived from older rocks when they have been determined by Mr. Joseph Wright. I once sent him some Essex boulder clay, and he reported a number of species as derived from the Chalk and a list of others as indigenous to the clay. Mr. J. Wright is not likely to make the mistake suggested.

That the belief in the marine origin of boulder clay has been and is rejected by the majority of British glacial geologists is fully admitted in my paper. Professor Kendall asks to whom I referred as upholders of the marine origin of boulder clay. Professor Bonney's Presidential Address to the British Association in 1910 shows that the marine theory has been consistently supported by high authorities. My own partial acceptance of the view has been by no means consistent, for I at first regarded all boulder clay as terrestrial, and was only gradually led to the view that some of it is marine. Amongst men with an intimate knowledge of the boulder clay of the south-west of Scotland, and who regard it as a marine deposit, may be mentioned Mr. J. Neilson, for the Glasgow district, and Mr. John Smith, after his detailed study of the Ayrshire Drifts. The increasing faith in isostatic oscillations has also encouraged the probability of a glacial subsidence. In recent years there seems to have been a decided trend toward the opinions that the boulder clay has not yet been satisfactorily explained, and that some of it is marine. The consequences of that conclusion are not so startling as Professor Kendall suggests, for until the shell beds at 1,300 feet on Three Rock Mountain, near Dublin; at Moel Tryfaen, Oswestry,

and Clava are adequately explained without submergence, there is nothing improbable in a 400 foot submergence of the Central Plain of Ireland. Carvill Lewis adopted a 400 foot Irish submergence during the advance of the ice (*Glac. Geol.*, p. 148).

The chief difficulty in the marine origin of Irish boulder clay is its poverty in marine fossils; but the references quoted in my paper show that marine fossils are widely scattered in the Irish drifts. They are rare, and to explain their rarity I quoted from men so experienced in polar biology as Dr. Nansen and Mr. J. Murray to show that under some conditions life is absent from the Polar seas. Dr. Nansen's statements that the floor of parts of the Arctic Sea are lifeless are not refuted by Gran having found the opposite in "samples taken later during the expedition". Similarly, in the Antarctic, Murray's statement that the shore deposits at Cape Royds contain no vestige of life is not refuted by the occurrence of shells elsewhere and in beds which, owing to the scarcity of life along the shore, Hedley and Priestly reject as beaches and attribute to upheaval and upthrust. Even in the Swedish drifts, though shells are usually abundant, the clays are sometimes sterile over large areas.

The marine origin of the Irish boulder clay is a subsidiary issue; the object of my paper was to show by a description of the internal structure and field relations of representative Irish eskers, that the most important were not formed along intra-glacial rivers, but on the margin of the ice, where it ended in a sheet of water. Most of the eskers in fact are kames, not osars. I fully recognize that the evidence for the sheet of water being the sea is less clear than that as to the nature of the eskers. I only advance the view that it was the sea as being more probable than that it was a series of glacial lakes; and there is nothing in Professor Kendall's note to modify that opinion. I regret his adoption of a tone of discussion which seems to me as out of date as the view that all boulder clay may be simply explained as *moraine profonde*.

J. W. GREGORY.

THE AGE OF THE SHENLEY LIMESTONE.

SIR,—It is fortunate that the Shenley echinoderms have received expert examination, and our thanks are due to Professor H. L. Hawkins for his note on the subject in your February issue (p. 57). I will, however, ask for temporary suspension of judgment in respect to his deductions as to the age of the deposit.

As the result of recent work, I shall be able to communicate to the Geological Society during the present session a paper containing much new evidence, both stratigraphical and palæontological, to prove that the limestone is in its proper position below the Gault, and that the Gault of the section belongs to the Lower and not, as supposed, to the Upper Gault.

G. W. LAMPLUGH.

ST. ALBANS.

February 10, 1921.

OBITUARY.

Sir Lazarus Fletcher, Kt., M.A., F.R.S., etc.

BORN MARCH 3, 1854.

DIED JANUARY 6, 1921.

BY the death of Sir Lazarus Fletcher, of heart-failure, at Grange-over-Sands, Lancashire, on January 6, mineralogical science has lost one of its ablest exponents. The famous series of Introductions to the Study of Meteorites, Minerals, and Rocks respectively, which he prepared at intervals after he became Keeper of the Mineral Department in the British Museum, have been the most efficient means for bringing the elementary principles of the science before the public, while for advanced students his treatise on double refraction, *The Optical Indicatrix and the Transmission of Light in Crystals*, has revolutionized the teaching of physical optics. Although he has thus been, and will continue to be as long as these guide-books are published, the means of arousing an interest in minerals in others, it may be said of him, as of many other mineralogists, that he was a mathematician first and a mineralogist afterwards. In order to appreciate fully the beauty, variety of form, and mutual relations of minerals, some knowledge of mathematics, physics, and chemistry is essential. Fletcher's distinguished career at school and college gave him to perfection this preliminary training, and it was not until after he had taken his degree at Oxford that he was first led to the study of crystals and thence was attracted to minerals.

Sir Lazarus Fletcher was born at Salford, Manchester, on March 3, 1854. At the age of eleven he entered the Manchester Grammar School, and during the next four years displayed such brilliance as a scholar that, instead of being launched upon a business career in that commercial centre as contemplated by his father, he was allowed, by the advice of the headmaster, to continue his studies, with the result that at the early age of seventeen he obtained a Brackenbury Science Scholarship at Balliol. His career at Oxford was signalized by first classes in mathematical Moderations and in the final schools of mathematics and natural science. After taking his degree he became demonstrator in physics to Professor Clifton in the Clarendon Laboratory, and Millard lecturer in physics at Trinity College, and was made a Fellow of University College. His work in the Clarendon Laboratory attracted the notice of Story Maskelyne, who at that time was acting both as Professor of Mineralogy at Oxford and as Keeper of the Mineral Department of the British Museum in London; and in 1880 Fletcher, after serving two years as assistant, on Maskelyne's retirement became the Keeper of the Department. It was at first a troublous heritage to which he had succeeded, for almost immediately he was confronted with the formidable task of removing the mineral collections from

Bloomsbury and arranging them in their new home at South Kensington. This transference and rearrangement skilfully accomplished, time was afforded him for the preparation of the celebrated guide-books and the selection and arrangement of the series of specimens to illustrate them. In the intervals of this work he was able to prosecute his crystallographic investigations of minerals and those chemical analyses of meteorites which are characterized by the meticulous care which he brought to bear upon any scientific work he undertook. In recognition of his services to science, in 1889 he was elected a Fellow of the Royal Society, in 1894 was chosen as President of the Geological Section of the British Association at its meeting in Oxford, and in 1912 was awarded the Wollaston medal of the Geological Society. After the retirement of Sir Ray Lankester in 1909 he became the Director of the Natural History Museum, and in 1916 was knighted. A few years before his promotion to the Directorship of the Museum he had been attacked by that heart-trouble which had the effect of sapping his energies during the rest of his career, and was eventually the cause of his death. This took place in his native country, the North of England, to which he had returned with his wife and daughter after his retirement from the Museum less than two years ago.

Fletcher's genial and amiable disposition and dry North Country humour endeared him to friends and colleagues. As characteristic examples of this quiet humour the following passages from the address delivered to the Mineralogical Society on his retirement from the Presidency in 1888 may be quoted: "It may be cast in our teeth that the volume (of the Society's Journal) is small, but one can proudly and truly retort that few volumes of the same size furnish so vast an amount of heavy reading," and again: "The Ancients, not unwisely, refrained from the invention of printing; they recognized . . . that their duty to posterity was to transmit to it only their masterpieces; when even these became burdensome, an incendiary, doubtless a librarian, quickly reduced their volume." Fletcher was put in a position of authority over others early in life, and happy was the lot of those who were fated to work under his direction. No bitterness or ill-feeling ever arose to mar their friendly intercourse, for irritability of temper was not in his nature, and the scrupulous regard for fair-play which characterized his relations with his assistants may be judged from the following extract from one of his reports: "After the Assistant has come on duty I have encouraged him in precise rather than in voluminous scientific work, and have taken care that he has had the sole credit of any work he has done. Further, to avoid the possibility of development of difficulties between the Assistant and myself, no one has been allowed to give me the least help in any scientific work which I have myself taken in hand." For the prosecution of such work he possessed in the highest degree that capacity for taking infinite pains which is supposed to be the attribute of genius. The elaborate

method which he adopted for the analysis of meteoric stones, and which he described in detail for the benefit of others engaged in similar work, was one which it is to be feared could appeal to few who were not possessed of his own skill and infinite patience. For many years previous to his retirement from the Museum he had devoted much thought to the problem of the classification of minerals, and with his usual thoroughness had critically examined every system which had been entertained during the last 200 years. During the last year of his life he had made some effort towards the completion of his task, and it is to be hoped that it may be possible to prepare for publication something of interest, at any rate from a historical point of view, from the manuscript which he has left behind.

The Mineralogical Society owes Fletcher a special debt of gratitude for the work which he did on its behalf. As one of its earliest members, its President from 1885 to 1888, and its Secretary for more than twenty years afterwards, he worked indefatigably first to establish the Society on a firm basis, and then to promote its interests.

Loyalty to friends and to any institutions with which he was or had been connected was one of the guiding principles of Fletcher's life. After he had attained to an assured position he was ever ready to help those from whom he may have received benefit in his youth, and the school and college in which he was educated. No one in trouble ever appears to have appealed to him in vain. Partly as a consequence of this open-handed generosity and partly, no doubt, from choice, his home life was always a very quiet and simple one. He was twice married, first to Miss Agnes Ward Holme, who died in 1915, leaving one daughter, and afterwards to her sister Edith. His wife and daughter survive him.

G. T. PRIOR.

James Reeve, F.G.S.

BORN MAY 12, 1833.

DIED DECEMBER 19, 1920.

MR. JAMES REEVE, F.G.S., Consulting Curator of the Norwich Castle Museum, died at Norwich on December 19, 1920, in which city he was born on May 12, 1833.

The 27th Annual Report of the Committee of the Norfolk and Norwich Museum for 1851 records that James Reeve, Assistant, had been appointed Curator in succession to Mr. H. J. Bellars, who had resigned. This appointment he held with conspicuous success until 1894, when the collections were transferred to the Town Council of Norwich and housed in the splendid buildings known as the Norwich Castle Museum, which was opened to the public on October 23, 1894, by the Duke and Duchess of York (the present King and Queen). Mr. James Reeve received the appointment as Curator under the Town Council, and by his energy and unrivalled knowledge

of local art was able to bring the collections up to a high state of efficiency. He retired in 1910 from active duties, and was appointed Consulting Curator, which appointment he held at the time of his death.

The account books of the Norfolk and Norwich Museum show that James Reeve commenced his duties at this Museum on Monday, November 8, 1847, so that he was officially connected with the Museum for seventy-three years—surely a record !

In the early years of his life he appears to have been a keen collector of land and freshwater molluscs from the lanes, woods, meadows, and streams in the neighbourhood of Norwich. He also worked assiduously for thirty years collecting shells from a Crag Pit he discovered at Bramerton, near Norwich, a locality already made classic by the work of Searles V. Wood and Samuel Woodward. His collection from this pit is one of the greatest treasures of the Norwich Museum, and he was very proud of one of his rare finds being determined by S. V. Wood as a new species and named in his honour *Odostomia reevei*.

On April 26, 1864, the Norwich Geological Society was established, with the Rev. John Gunn, F.G.S., as President, John Ellor Taylor Secretary, and James Reeve an active member of the Committee. The Society flourished until 1884, when it became merged into the Norfolk and Norwich Naturalists' Society, established in 1869, a Society of which James Reeve was an original member and a Vice-President at the date of his decease. He was elected an F.G.S. in 1901, and was interested in F. W. Harmer's Memoir on Pliocene Mollusca, published during recent years by the Palæontographical Society. His original papers were published in the *Proceedings of the Norwich Geological Society*, 1878-84, and innumerable references to him are to be found in the Memoirs of S. V. Wood, F.G.S., F. W. Harmer, M.A., F.G.S., and E. T. Newton, F.R.S.

The geological collections of the Norwich Castle Museum consist mainly of fossils of local origin, viz. Cromer "Forest Bed", Chalk, and "Crag", one of the most important being that formed by Samuel Woodward, author of the *Geology of Norfolk*, published as early as 1833.

The present Curator, Mr. Frank Leney, has added considerably to the geological collection since his succession in office to Mr. James Reeve, and has published lists of all specimens preserved in the Norwich Castle Museum which have been figured by Darwin and others.

Of Mr. James Reeve's labours as an art connoisseur, and the very valuable collection he formed of the Norwich School of Painters, let the prints and drawings in the British Museum and the Norwich Castle attest to his untiring efforts to rescue from oblivion and bring together the works of Crome, Cotman, Stark, Stannard, and others, who made a name for the Norwich school.

F. L.

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APRIL, 1921.

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THE
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EDITORIAL NOTES.

OWING to the incidence of the Easter holidays in the last week of March, we are obliged this month to go to press at an unusually early date. Consequently one or two items which should normally have been included in this number are unavoidably postponed. For this we wish to express our regrets.

* * * *

THE list of fifteen candidates nominated by the Council for election to the Royal Society, published just too late to be mentioned in our March number, includes the name of only one geologist, Mr. C. S. Middlemiss, C.I.E., late of the Geological Survey of India and now Superintendent of the Mineral Survey of Kashmir. To him we tender our hearty congratulations. It will be remembered that last year no geologist received the honour of election. There is a widespread feeling that the state of affairs with regard to the number of candidates now awaiting election is in need of careful consideration by the Council of the Royal Society. In the list issued last February there are 118 names, belonging to nearly thirty distinct categories. Of these the largest number (23) belong to the medical profession; 20 to the chemists, 10 to the electrical and civil engineers, 10 to the geologists, 10 are botanists, 8 zoologists, 7 mathematicians, 7 physiologists, 2 mineralogists, 4 naval architects, 3 entomologists, and about 12 of unique scientists (including one veterinary surgeon). Many of these have been suspended for three or four years, and as only fifteen are elected annually, a large proportion stand very little chance of admission within a reasonable time, if ever. Whether the enormous importance attached by the scientific world to the Fellowship of the Royal Society is ultimately to the benefit of science in general is a matter that we do not propose to discuss; the fact remains that it is the heart's desire of all scientific men, and we would respectfully suggest to the Council that the time has now arrived when they might well consider the possibility of a substantial addition to the number of annual elections. Far be it from us to advocate any lowering of the standard; our point is that the number of those fully qualified has of late increased so greatly that many men as good as or even better than those elected a few years ago are now perforce left out in the cold, to the great discouragement of themselves and of the coming generation who have not yet reached the stage of candidature. In our opinion the Fellowship of the Royal Society should be regarded as an encouragement to future effort, as well as a reward for meritorious work in the past.

ORIGINAL ARTICLES.

On Cycles of Sedimentation in the Eocene Strata of the Anglo-Franco-Belgian Basin.

By L. DUDLEY STAMP, M.Sc., A.K.C., F.G.S., King's College, London.

(Continued from p. 114.)

III. THE EOCENE SUCCESSION IN EACH AREA.

A. THE PARIS "BASIN".

The Eocene deposits of the Paris region group themselves naturally into six cycles:—

	<i>Marine representatives.</i>
Bartonian	{ Calcaire de Ludes.
	{ Sables de Marines.
Ledian (Auversian) . .	Sables d'Auvers (Sables moyens
	or Sables de Beauchamp).
Lutetian	Calcaire grossier.
Ypresian	Sables de Cuise.
Landenian	Sables de Bracheux.
Montian	Calcaire pisolitique.

The beds are predominantly marine towards the north and predominantly continental towards the south and south-east. At Verzenay,¹ near Reims, in the south-east, there is practically a complete succession of continental deposits from the Landenian to the Bartonian.

The diagram (Fig. 2, p. 147) shows in more detail the grouping adopted for the Eocene beds of the Paris region. It is adapted from the work of Leriche, and is the grouping now generally accepted on the Continent.²

Montian.—The Montian (Calcaire pisolitique) is now only found in a few isolated patches and seems to have been deposited in certain areas rather than over the whole Paris region. In some respects the fauna is intermediate between the Cretaceous and the Eocene. There are some curious anomalies in the situation of some of the deposits of this age, which tend to suggest localized formation in shallow lagoons left during the retreat of the Cretaceous sea.

It is simpler, for this reason, to commence the diagram with the next cycle—the Landenian.

Landenian.—The Lower or Marine Landenian consists of glauconitic sands, often argillaceous towards the base and tending to be harder in the lower part and to form beds of "tuffeau". Glauconite becomes less abundant in the higher parts. The Lower Landenian has been divided into three zones:—³

3. Zone of *Cyprina scutellaria*.
2. Zone of *Pholadomya Konincki*.
1. Zone of *Cyprina Morrisi*.

¹ Leriche, "Observations sur les Terrains tertiaires des environs de Reims et d'Épernay": *Ann. Soc. géol. Nord*, vol. xxxvi, 1907, p. 367.

² Compare Lemoine, *Géologie du Bassin de Paris*, 1911, p. 200.

³ Leriche, "Sur les Horizons paléontologiques du Landénien marin du Nord de la France": *Ann. Soc. géol. Nord*, vol. xxxii, 1903, p. 239.

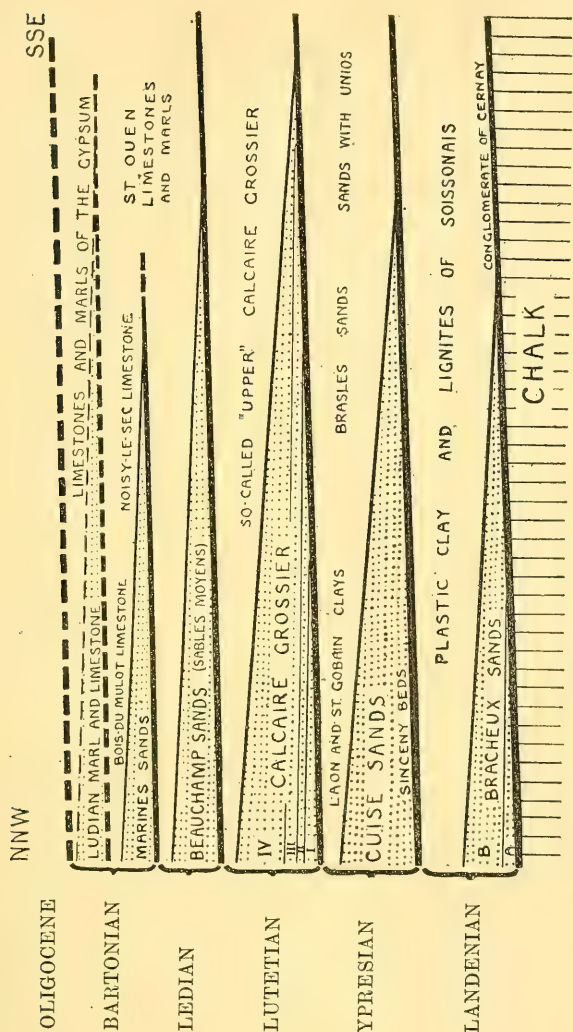


FIG. 2.—Cycles of sedimentation—Paris Basin (in part after Leriche). Landenian Zones: A = zone of *Pholadomya Konincki*; B = zone of *Cyprina scutellaria*. Lutetian Zones: I = zone of *Martia Omaliusi*; II = zone of *Nummulites levigatus*; III = zone of *Dittrupa strangulata*; IV = zone of *Cerithium giganteum*.

Deposits of the earliest zone are not found in the main region of the Paris Basin, but only in North France and Belgium. The transgression continued later, so that the basal deposits in the extreme north-eastern part of the Paris Basin belong to the zone of *Pholadomya Konincki* (Tuffeau de La Fère). The beds of the highest zone occur over a far more extensive area. In the Paris Basin they are known as the Sables de Bracheux and the Sables de Châlons-sur-Vesle. Professor Leriche has prepared a very instructive series of

maps, showing the distribution of the various marine Eocene beds in the Paris and Belgian regions;¹ and the map showing the distribution of the zones of the Landenian demonstrates very clearly the successive overstep in all directions.

The Upper Landenian (the so-called Sparnacian) marks a silting up of these shallow seas. Broad, shallow lagoons teeming with estuarine molluscs existed over a very large part of the great basin, and in them were deposited sediments of the type of our Woolwich Beds. Round them there is the broad band of lacustrine and fluvatile deposits of Reading type. The Upper Landenian was the most extensive, geographically, of all the continental episodes. The extent of marine waters in the centre of the basin must have been very small indeed. Almost the only locality now remaining where the whole of the Landenian is marine is the Isle of Thanet.

The marine Landenian has been called Thanetian on the supposition that it corresponded to the Thanet Sands of the London Basin. As Prestwich² and others have pointed out, the zone of *Cyprina scutellaria* is represented in England by the Bottom Bed of the Woolwich Series. The author has recently adduced further proof of this correlation.³ The name Thanetian must therefore be dropped. It follows also that the "Sparnacian" deposits of the French do not correspond exactly to our Woolwich and Reading Beds.

Ypresian.—When one remembers the very large area covered by the shallow lagoons of Upper Landenian times, it is clear that even a slight disturbance would cause a very great change in the distribution of land and water. This question has been dealt with at some length elsewhere,⁴ and it is sufficient to note here one or two of the more important conclusions. The waters of the invading Ypresian sea flooded very rapidly over the Upper Landenian lagoons. There are extensive accumulations of well-rolled flint-pebbles, and elsewhere very fine or well-washed sands, showing the disturbed conditions which prevailed at the time. For a short time the incoming marine fauna lived side by side with the existing fauna of the lagoons, and one gets the curious mixed fauna of the Sables de Sinceny. These basal Ypresian beds compare very closely with their equivalents in England—the Blackheath Beds. It is interesting to note that this distinctive fauna, associated with the peculiar type of lithology of the beds (that is beds of unbleached, well-rounded flint-pebbles), is restricted in geographical distribution to areas of pre-existing estuarine lagoons. Where the Ypresian sea invaded

¹ Leriche, *Bull. Soc. géol. France*, sér. iv, vol. xii, 1912, pls. xxiii-xxvii.

² Prestwich, *Quart. Journ. Geol. Soc.*, vol. xlv, 1888, pp. 98-9.

³ Stamp and Priest, "Geology of the Swanscombe Eocene Outlier": *Proc. Geol. Assoc.*, vol. xxxi, 1920, p. 187.

⁴ Stamp, "On the Beds at the Base of the Ypresian in the Anglo-Franco-Belgian Basin": read at the meeting of the Geologists' Association, July 2, 1920. *GEOL. MAG.*, Vol. LVII, 1920, p. 380 (in the Press).

regions of Upper Landenian fluviatile or lacustrine beds (e.g. mottled clays) the mixed fauna of the Sables de Sinceny does not occur, and the fossils from the base of the Ypresian are entirely marine.

Apart from these basal beds the Ypresian is represented in the Paris Basin by a series of sands—the Sables de Cuise (*sensu lato*). It is characterized by the occurrence of *Nummulites planulatus* d'Orb.—*elegans* Sow.¹ The change from the disturbed conditions which prevailed during the deposition of the Sables de Sinceny to the more tranquil conditions of the Sables de Cuise is marked by the existence in many localities of a thin basal bed to the last-mentioned sands. In exactly the same way the London Clay of the London Basin retains its own basement bed even when resting on the Blackheath Beds. The Sables de Cuise are glauconitic sands, sometimes coarse, especially near the base, but on the whole remarkably fine-grained.

The Cuise Sands are succeeded by presumed continental deposits—a bed of greenish clay without fossils (Argile de Laon or de Saint Gobain), or by sands with fluviatile fossils (Sables à Unios et Térédines).

Lutetian.—The Lutetian is the famous Calcaire grossier of the Paris Basin. It generally commences with a coarse glauconitic sand, containing pebbles or rolled fossils at the base. The marine Lutetian consists of varied calcareous beds, of which the best-known is the shelly, foraminiferal limestone, so prized for building. Sandy limestones and calcareous sands are of common occurrence. Although characterized throughout by the presence of *Nummulites lævigatus* Lamk.—*Lamarcki* d'Arc., this fossil is especially abundant at one horizon. Leriche has shown that this marine Lutetian is divisible into four zones :—²

4. Zone of *Cerithium giganteum*.
3. Zone of *Ditrupea strangulata*.
2. Zone of *Nummulites lævigatus*.
1. Zone of *Marettia Omaliusii*.

The zone of *Nummulites lævigatus* constitutes a bed a few metres thick, consisting almost entirely of the zone-fossil. It is known as the “Pierre à liards”, and is a very easily recognized horizon. The geographical distribution of the zones demonstrates beautifully the successive overlap; the first zone only just reaches the Paris Basin, while the higher zones have successively wider distribution.³ The succeeding continental beds are the so-called Calcaire grossier *supérieur*, and comprise thin-bedded limestones with estuarine fossils (especially *Cerithium*). Towards the periphery of the basin these pass into unfossiliferous mottled clays and marls.

¹ In most cases the megalospheric and microspheric forms of each species of *Nummulites* have been described under different names. In this paper the double name is given on the first occasion of reference to the species, but, for the sake of brevity, the more usual name is generally used.

² Leriche, op. cit., 1912, p. 700 (with references).

³ Leriche, op. cit., 1912, pl. xxv.

Ledian (Auversian).—The lagoon areas of the Upper Calcaire grossier were invaded by the sea, which deposited the Sables de Beauchamp. These beds are characterized by the occurrence of *Nummulites variolarius* Sow.—*Heberti* d'Arc. In the Paris Basin they generally consist of clean sands (sometimes calcareous), but appear to have been formed in shallower water than was the case with the earlier marine invasions. In places, therefore, they are more markedly false-bedded and frequently coarse. The succeeding continental deposit is a well-marked fresh-water limestone—the Calcaire de Saint Ouen—with *Limnæa* (*L. longiscata*) and *Planorbis*.

Bartonian.—When considering the highest beds of the Eocene strata in the Paris region, it is necessary to bear constantly in mind the more specialized conditions which prevailed during their formation. The marine invasion of the Ledian is very distinct, but the fauna has a shallow-water aspect. In other words the basin was becoming silted up. This is still more apparent in the succeeding stage—the Bartonian. One has all the phenomena of the partial drying-up of an enclosed sea, culminating in the deposition of enormous masses of gypsum. Interstratified with the latter one finds beds of marl with marine fossils (Ludian or Marne à *Pholadomya ludensis*). The fossils differ slightly from those found in the lower part of the stage, but the differences are such as one would expect to result from local evolution *in situ* in response to unfavourable conditions. It is not difficult to see why the highest series of the Eocene beds has been much discussed and numerous correlations proposed.

It is far better, therefore, to take as the type of the highest part of the Eocene the Hampshire sequence. There one has a perfectly natural cycle of sedimentation, commencing with the marine invasion of the Barton Clay (horizon of *Nummulites Orbigny* Gal.—*wemmelensis* De la Harpe, = *N. prestwichianus* Rupert Jones, = *N. elegans* Sow. var. *Prestwichii* Rupert Jones), passing upwards into the shallower-water conditions of the Barton Sands (Long Mead End Beds), which, in turn, fade gradually into the continental conditions of the Lower Headon Beds. The stage is very clearly defined by the abrupt change at the base of the next marine invasion, that of the Middle Headon Beds.

Briefly, in the Paris Basin there is a lower series of marine sands—the Sables de Marines—the fauna of which differs but slightly from that of the Ledian, but in which *Nummulites variolarius* does not occur. These are succeeded by a series of marls and gypseous beds. Amongst the marls there is a thin, but constant, bed of marl or limestone—the Marne à *Pholadomya ludensis* or the Calcaire de Ludes—with marine fossils. The existence of this limestone has caused it to be said that there are two cycles in the highest Eocene of the Paris Basin, a lower or Marinesian (*sensu stricto*) and an upper or Ludian. If one examines the Calcaire de Ludes in the field, however, as at Verzenay (near the type locality of Ludes), one finds

an ill-defined band grading both upwards and downwards into fresh-water limestone. Stratigraphically, therefore, the creation of a separate stage seems unwarranted. Moreover, as Dollfus¹ has shown, there are no really new elements in the Ludian fauna, at the most some variations from the typical forms of the Sables de Marines. It is important to note, however, that both Dollfus² and Leriche³ wish to include our Middle and Upper Headon Beds with the Eocene as part of the Bartonian (Leriche) = Marinesian of Dollfus.

Now there is absolutely no doubt that the Bartonian Cycle closes with the Lower Headon. The Middle Headon Beds (including the Brockenhurst Beds) commence a fresh cycle. The classification of the French beds must depend on the age assigned to the Middle Headon Beds. At present the author is strongly inclined to agree with Boussac⁴ that the Middle Headon Beds mark the base of the Oligocene, and that the Ludian is exactly equivalent to the Barton Sands (Long Mead End Beds). This agrees with the old opinion of von Koenen,⁵ and with the more recent opinion of White,⁶ that the lowest zone of the Middle Headon (Brockenhurst Zone) contains the most clearly marine fauna in the British Oligocene. The correlation therefore stands thus:—

	<i>Paris Basin.</i>	<i>Hampshire.</i>
OLIGOCENE . . .	Marls above the Gypsum.	Middle Headon Beds (including Brockenhurst Beds).
EOCENE— Bartonian { Ludian . . . { Bartonian { (<i>sensu stricto</i>)	Ludian marls with gypsum Sands of Marines and Cresne	Lower Headon Beds and Barton Sands Barton Clay.

It is only fair to state the other possible classification is as follows:—

¹ Dollfus, "Excursion to Paris": *Proc. Geol. Assoc.*, vol. xxi, 1909, p. 12. The writer is indebted to M. Dollfus for further unpublished information on this question.

² Dollfus, "On the Classification of the Beds of the Paris Basin": *Proc. Geol. Assoc.*, vol. xxi, 1909, pp. 107–12.

³ Leriche, "Observations sur la Classification des Assises paléocènes et éocènes du Bassin de Paris": *Ann. Soc. géol. Nord*, vol. xxxiv, 1905, p. 391.

⁴ Boussac, "La Limite de l'Eocène et de l'Oligocène": *Bull. Soc. géol. France*, sér. iv, vol. vii, 1907, p. 400.

⁵ Von Koenen, "Ueber die Parallelisirung des norddeutschen, englischen, und französischen Oligocäns": *Zeitsch. d. deutsch. geol. Gesells.*, 1867, pp. 23–32.

⁶ White, *Geology of the Country near Lymington and Portsmouth* (Mem. Geol. Surv.), 1915, p. 43. More recently White has adopted the correlation of Dollfus (1909), *Handb. Reg. Geol.*, Band iii, i Abt.: The British Isles, p. 272 (1917).

		Paris Basin.	Hampshire.
OLIGOCENE . . .		Marls above the Gypsum.	Bembridge and Hamstead Beds.
EOCENE— Bartonian	Ludian . . .	Limestone and marls of the gypsum with <i>Phol. ludensis</i> .	Upper Headon Beds and Middle Headon Beds.
	Bartonian (<i>sensu stricto</i>)	Limestone of Noisy-le-Sec, etc. Sands of Marines and Cresne.	Lower Headon Beds. Barton Sands. Barton Clay.

It seems unwarrantable to use the much misused term Bartonian to include also all the Headon Beds as Leriche¹ has done. Those who insist on grouping all these beds together with the Barton Clay and Sands as Eocene, would do better to employ the term Marinesian of Dollfus.²

In any case our Lower Headon Beds must be linked with the Barton Sands as Eocene, and part of the Bartonian cycle. Also the Middle Headon Beds must be regarded as the commencement of a separate cycle.

B. THE HAMPSHIRE "BASIN".

The Hampshire Basin is particularly suited to the study of cycles of deposition. There are at least four continuous sections of practically the whole of the Eocene sequence in the sea-cliffs—one from Studland Bay round Bournemouth Bay to Highcliffe and Barton (Long Mead End), a second in Alum Bay at the western end of the Isle of Wight, a third in Whitecliff Bay at the eastern end of the Isle, and a fourth in Bracklesham Bay and the coast of Chichester Harbour to the north. Some of the lower beds are also seen further west, in Dorset, and further east in the outliers near Newhaven, Sussex. These sections lie approximately along a west and east line, from a predominantly continental sequence in the west to an almost completely marine one in the east. The outliers at Newhaven also are closely linked stratigraphically with those near Dieppe, on the other side of the English Channel.

The accompanying diagram (Fig. 3, p. 153) shows how naturally the Eocene deposits of the Hampshire Basin group themselves into cycles. The variations in thickness of the various beds conform to the theoretical requirements to a remarkable degree, especially when one remembers there is considerable distortion due to folding.

Landenian.—The Landenian is represented in the Hampshire Basin by a series of mottled clays and coarse, false-bedded sands of fluvial origin (Reading Beds). In the west (Dorset and Devon³)

¹ Leriche, *op. cit.*, 1905, p. 391.

² Dollfus, *op. cit.*, 1909, p. 107.

³ Reid, *Quart. Journ. Geol. Soc.*, vol. lii, 1896, p. 490; *ibid.*, vol. liv, 1898, p. 234.

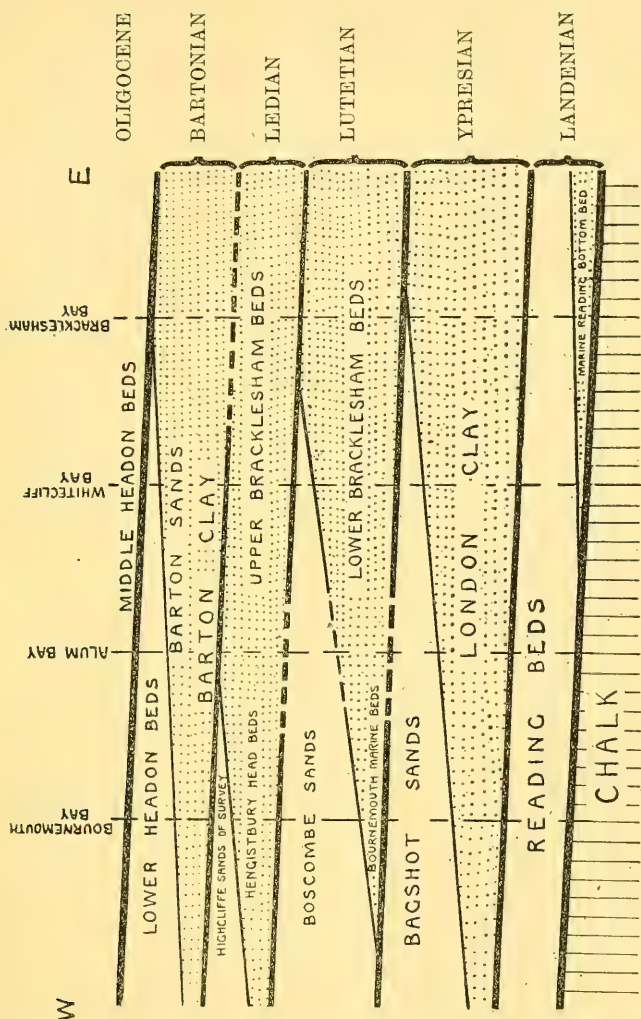


FIG. 3.—Cycles of sedimentation—Hampshire Basin.

these pass into coarse gravels, etc. In the extreme east, as at Newhaven, the mottled clays give place to well-bedded clays crowded with estuarine shells (Woolwich Beds), and similar beds occur at Dieppe. At the base of the series there is a thin bed of greenish or brownish glauconitic sand, resting on an irregular surface of Chalk. Some small rolled green-coated flints occur at the base, as well as angular flints left after the sub-surface solution of the Chalk, and the bed is obviously marine. As Parent¹ has pointed out, it is

¹ Parent, "Notes sur les Terrains Tertiaires du Pays de Caux": *Ann. Soc. géol. Nord*, vol. xxii, 1894, p. 9.

certainly a continuation of the Sables de Bracheux (zone of *Cyprina scutellaria*). This was recognized also by Prestwich. About 33 feet thick at Newhaven, it is generally hidden by slips at Whitecliff Bay, and has decreased to about 4 feet at Alum Bay. The enormous marine transgression which took place at the time of formation of the Bracheux Sands has been pointed out above. Here, in the Hampshire Basin, the evidence for the transgression is equally well marked, and also the rapid filling up of the shallow sea with fluvial and estuarine deposits.

Ypresian.—The marine invasion of Ypresian times in England was one of the most extensive of all the Eocene invasions, yet the unconformity is very slight. As White¹ has pointed out, the estuarine and freshwater flats of late Landenian times favoured a rapid yet tranquil marine invasion. The conditions for the existence of the mixed Blackheath fauna of the London Basin did not exist in the Hampshire Basin, i.e. the brackish-water lagoon phase of the Landenian only occurs to the extreme east, at Newhaven, etc. The region was too far from the Wealden uplift to receive great masses of pebbles such as one finds in the London Basin, hence the Blackheath Beds are absent. The mass of the London Clay commences with a thin sandy pebble-bed—the Basement Bed. The London Clay itself is generally somewhat sandy, especially in the west. It thickens steadily from west to east, from 80 to 100 feet at Studland Bay, 233 feet at Alum Bay, and 320 at Whitecliff Bay, to 340 feet at Portsmouth. It includes some beds of fine sand in the upper part and passes up quite gradually into the fluvial Bagshot Sands. As one would expect from their being continental deposits, the latter are very thick in the west, estimated at over 500 feet near Bournemouth, and they become thinner eastward, and are only about 100 feet thick in Whitecliff Bay and 30 feet at Portsmouth. To the north of Bracklesham Bay they are represented by a thin bed of sand a few feet in thickness between the marine deposits of the London Clay and Bracklesham Beds. The great mass of sands grouped under the term Bagshot Sands in the Alum Bay section undoubtedly include representatives of the Bracklesham Beds—both Lutetian and Ledian. The sands are decalcified and unfossiliferous, but it is hoped that a mineralogical examination of the sands may lead to a detection of glauconite, and indicate the marine origin of certain of the beds. The marine invasions of Lutetian and Ledian times are both very clearly seen in the Whitecliff Bay section, and are traceable as the Bournemouth Marine Series and the Hengistbury Head Beds respectively in the Bournemouth Bay section, hence they must be represented in Alum Bay.

The London Clay in the neighbourhood of Portsmouth—so ably studied by Meyer²—exhibits several interesting features. There

¹ White, op. cit., 1915, p. 11.

² Meyer, "On the Lower Tertiary Deposits recently exposed at Portsmouth": *Quart. Journ. Geol. Soc.*, vol. xxvii, 1871, p. 74.

are three pebble-beds which permit of a triple division of the clay. Each division commences with a layer of pebbles, followed by stiff clay, which becomes sandy in the upper part, passing into a sand. White¹ emphasizes these variations in lithology and points out that they indicate a change from comparatively deep water to shallower-water conditions—or “shoaling”—and he actually refers to them as “cycles of deposition”. At the same time White points out that these pebble-beds are constant neither in number nor in position. It is interesting to note that they increase in number as one approaches the area of the Wealden Dome, and there can be little doubt that that was the source of the pebbles, and that gentle movements of uplift during Ypresian times were responsible for the changes in lithology. It must be emphasized that these slight variations in the mass of the clay do not constitute cycles of deposition.

Lutetian.—No apology is needed for dividing the Bracklesham Beds into two divisions. Previous observers have already made this separation, and Leriche,² White,³ and others have correlated the two divisions with the French succession of Lutetian and Ledian (Auversian). The first-mentioned beds are characterized by the presence of *Nummulites lævigatus*, the second by the presence of *N. variolarius*. These two species never occur together. The Lutetian invasion is marked by a basal pebble-bed or pebbly glauconitic sand at Bracklesham and Whitecliff Bays, and is very distinct. Remembering the enormous amount of sediment which was being brought from the west and being deposited as the Bagshot Sands in the neighbourhood of Bournemouth, it is not surprising that the marine sediments of the encroaching sea should be mixed with, and partly masked by, the continental deposits. Even as far east as Whitecliff Bay one finds the basal glauconitic bed of the Lutetian succeeded by “green sand and laminated clays with seams of lignite”⁴ (Fisher’s Bed III), and passing further west the separation of the marine beds becomes more difficult. As mentioned above, the representatives of the marine Lutetian have not been clearly distinguished in Alum Bay. Passing across to Bournemouth Bay, the Bournemouth Marine Beds evidently mark the Lutetian marine invasion, but are at almost the western end of the sea, or, as White puts it, the beds represent “the seaward facies of a deltaic formation such as the Freshwater Series”.⁵

¹ White, loc. cit., p. 11.

² Leriche, “Observations sur la Géologie de l’Île de Wight”: *Ann. Soc. géol. Nord*, vol. xxxiv, 1905, p. 16.

³ White, loc. cit., p. 20.

⁴ Fisher, “On the Bracklesham Beds of the Isle of Wight Basin”: *Quart. Journ. Geol. Soc.*, vol. xviii, 1862, p. 65.

⁵ White, “Geology of the Country around Bournemouth,” 2nd ed. (*Mem. Geol. Surv.*), 1917, p. 29. The Bournemouth Freshwater Series is situated in the upper part of the Bagshot Sands.

In Bracklesham Bay the Lutetian and Ledian Series are not separated by any continental deposits, but there is a faunal break.¹ In Whitecliff Bay the marine Lutetian passes up into a succession of laminated sandy clays with lignitic seams in the upper part (Fisher's Bed VIII). The presence of underclays with rootlets in this division shows that there really was a recession of the sea towards the close of Lutetian, and that the vegetable matter was not simply drifted into these beds by marine currents. It was probably a swamp near sea-level. Near Bournemouth the break between the Lutetian and Ledian is marked by the Boscombe Sands, with their thick beds of coarse shingle. Some difference of opinion exists as to the conditions under which the Boscombe Sands were formed. The most obvious interpretation seems to the present writer to be that of subaerial shingle-banks, left by the retreating Lutetian sea. The extraordinary bleaching and alteration of the pebbles, as well as the absence of glauconite in the accompanying sands, supports this idea rather than that of submarine shoals.

Ledian.—The palæontological break between the Lutetian (Lower Bracklesham) and the Ledian (Upper Bracklesham) is a well-marked one. Not only has one the two very distinct species of *Nummulites*—*N. lævigatus* characteristic of the former and *N. variolarius* of the latter—but the whole faunas are quite distinct. There are many Ledian species which do not occur in the Lutetian but which range up into the Bartonian. As several authors have pointed out, there is a more marked palæontological break between the Lutetian and Ledian than between the Ledian and Bartonian.

The Ledian is entirely marine in both Bracklesham and Whitecliff Bays. In Alum Bay there are 47 feet of glauconitic clays below the band with *Nummulites Prestwichii* (a band which is usually taken as the base of the Barton Clay). There is a strongly marked pebbled bed at the base of these clays. *Nummulites variolarius* has not been found in Alum Bay, and the present writer is uncertain whether this 47 feet of strata should be considered as representing the Ledian or whether it should be linked with the Bartonian. The Ledian seems to be represented in Bournemouth Bay by the Hengistbury Head Beds. The latter pass up into the Highcliffe Sands (of the Survey). The lower part of the latter show "wash-outs" and little seams of pipeclay, and on the whole presents a fluvial aspect. Although in the Highcliffe section obscure casts of marine fossils are said to have been found, these sands seem to represent a feeble development of continental Ledian. Certainly the continental Ledian is very poorly developed, and the break between the Ledian and Bartonian is principally palæontological.

Bartonian.—The Bartonian cycle has already been discussed. Stratigraphically it seems likely that the base in the Highcliffe

¹ Boussac, "Observations sur la faune des couches supérieures de Bracklesham à *Nummulites variolarius*": *Ann. Soc. géol. Nord*, vol. xxxvi, 1907, p. 360.



FIG. *a*.—Channel in Carboniferous Limestone, filled with sandstones and shales, the whole overlain by Trias. (Geol. Surv. Photo.)



FIG. *b*.—Carboniferous Limestone irregularly eroded, and overlain by sandstones and shales, now with a thin later covering of Trias. (Geol. Surv. Photo A 792.)

(Barton) section is the clearly defined pebble-bed towards the higher part of the Highcliffe Sands of the Survey. The glauconitic clays above this bed are strongly contrasted with the pale sands below. The *Nummulites Prestwichii* band is met with a few feet above, and so the pebble-bed and the few feet of clays between it and the Nummulite band are usually grouped in the upper part of the Bracklesham Beds. This seems curious, since the zonal Nummulite does occur, though sparingly, below its special band. Moreover, there is no lithological change at the Nummulite band, but a very obvious one at the pebble-bed below. This pebble-bed may be the same as the one seen in Alum Bay at the base of the 47 feet of doubtful beds.

The marine Bartonian beds (Barton Clay and Barton Sands) thicken steadily eastwards from 192 feet at Highcliffe (Barton) to 338 feet in Alum Bay and 368 feet in Whitecliff Bay. The first two figures are increased to 206 and 385 feet respectively if the pebble-bed is taken as the base of the Bartonian. The continental Bartonian (Lower Headon Beds) consists of freshwater limestones with *Limnæa*, marls, etc., and thins, as one would expect, from west to east; 82½ feet at Barton, from 61 to 82 feet in Alum Bay and on Headon Hill; it is reduced to 28 feet in Whitecliff Bay, and has become more estuarine.

Commencing with the Middle Headon Beds, the Oligocene deposits of the Hampshire Basin also seem to group themselves into cycles. The distribution of the zones of the Middle Headon agrees with the theory of a gradual transgression at that period, similar to the transgression observed in the Landenian or Lutetian. It is hoped to deal later with these beds.

(To be concluded.)

The Unconformity between the Millstone Grit and the Carboniferous Limestone at Ifton, Mon.

By E. E. L. DIXON, A.R.C.Sc., B.Sc., F.G.S.

(PLATE II)

INTRODUCTION

THE object of the present communication is to place on record a section, apparently unique, in which the unconformity between the Millstone Grit and Carboniferous Limestone that exists in parts of South Wales and Monmouthshire is clearly displayed. The exposure was first examined at the suggestion of the brilliant worker who threw so much light on Lower Carboniferous problems, the late Dr. Vaughan. The writer had explained¹ the attenuation of the Carboniferous Limestone Series in the Newport (Mon.) district as due to unconformable overstep by the Millstone Grit, similar to

¹ In "The Country around Newport" (*Mem. Geol. Surv.*), ed. 2, 1909, p. 20.

an overstep at this horizon that had already been observed near Haverfordwest, at the other end of the South Wales basin, by Professor O. T. Jones.¹ The value of the Ifton section in demonstrating that this overstep was widespread was recognized, and photographs, two of which are here reproduced, were secured by H.M. Geological Survey. Since then the unconformity at the eastern end of the South Wales coalfield has been confirmed by the detailed examination of a large area by Mr. F. Dixey and Dr. T. F. Sibly,² and has been found by the writer, in the course of work not yet published, to reach its greatest known extent in the Abergavenny district. Nevertheless, it seems desirable to describe the Ifton section because it is the clearest exposure known, in the whole of the South-West Province, of the unconformity between the Carboniferous Limestone and the Millstone Grit, and also on account of the remarkable inter-relations of the two formations which it reveals.

It should be observed that though the Ifton limestone-outcrop is continuous with that surrounding the Forest of Dean coalfield, the sandstones spoken of as "Millstone Grit" in the two areas, which are widely discontinuous, differ completely from one another in age and character. Those of the Forest of Dean have been shown by Dr. Vaughan³ and by Dr. Sibly⁴ to be Upper Avonian, the lower portion being correlated definitely by the latter worker with the upper *Seminula* subzone (S_2); he therefore justly separates the sandstones of the Forest of Dean from other "Millstone Grit" under the name of Drybrook Sandstone.

The Millstone Grit of Ifton cannot be placed palæontologically within narrow limits, but lithologically it resembles the Basal Grit of South Wales, which is the horizon also of the beds resting unconformably on the Carboniferous Limestone at Haverfordwest.

There is reason to believe⁵ that the Basal Grit is correlative with part of the Pendleside Series. When it is remembered that other rocks of the South-West Province included in the Millstone Grit are certainly later than all Avonian and Pendleside zones—though they may not be Middle Coal Measures as suggested by R. H. Goode⁶—it can be seen how necessary it is to distinguish between the different components of the barren series, separating Limestone from Coal Measures, which has been given the useful name of Millstone Grit.

The areal extent of the unconformity remains to be determined. The break exists at the eastern and western ends of the North Crop of the South Wales basin, but is presumably absent at those intermediate places along the outcrop where radiolarian cherts are

¹ In "The Country around Haverfordwest" (*Mem. Geol. Surv.*), 1914, p. 151.

² *Quart. Journ. Geol. Soc.*, vol. lxxiii, 1918, p. 111.

³ *Quart. Journ. Geol. Soc.*, vol. lxi, 1905, pp. 251-2.

⁴ *Geol. Mag.*, 1912, p. 417; *Geol. Mag.*, 1918, p. 25.

⁵ E. Dixon, "The Country around Pembroke and Tenby" (*Mem. Geol. Surv.*), 1921, chap. x.

⁶ *Quart. Journ. Geol. Soc.*, vol. lxix, 1913, pp. 272, 275.

developed at the base of the Millstone Grit. In Gower and South Pembrokeshire the junction is almost certainly conformable.

DESCRIPTION OF THE IFTON SECTION.

The exposures at Ifton, which lie $5\frac{1}{2}$ miles south-west of Chepstow, are disused parts of a quarry north-west of the junction of the roads from Caerwent and Magor. The formations present in the quarry are:—

3. *Trias*.—Brown, buff, or red friable sandrock and loose sand, up to 6 feet in thickness, the lowest few inches littered with angular fragments, chiefly of Carboniferous Limestone, Millstone Grit and impure limonite. They rest on an even platform eroded across Limestone and Grit alike, and doubtless represent a sandstone that forms the base of the Keuper Marl in this district, resting immediately on the Dolomitic Conglomerate where the latter is present.

2. *Millstone Grit*.—Hard sandstone, partly quartzitic and occasionally somewhat pebbly, with soft shales weathering to clay, both rocks raddled by ferruginous waters, the shales to purplish tones. The few moulds of plant-fragments present are generally small and indeterminable, but a large stem,¹ found *in situ*, has been identified by Dr. Kidston as a Carboniferous type, probably a *Lepidophloios*. The beds fill steep-sided channels and underground cavities, eroded in the Carboniferous Limestone, in the manner to be described later.

1. *Carboniferous Limestone*.—Limestones, chiefly oolites or amorphous-looking calcite-mudstones, with some "subsequent" (vein-) dolomite; in colour white, light-grey, or various red tones owing to raddling. All the beds appear to be free from *contemporaneously-deposited* sand. The fossils, of which *Seminula ficoides* Vaughan is the most abundant, and the rock-types show that they belong to the Seminula Zone, a conclusion to which Dr. Vaughan had come prior to my visit. The Dibunophyllum Zone, which in its normal development is characterised by distinctive fauna and rock-types, is certainly not represented by any part of the limestone.

The relations of the formations are illustrated by Pl. II (*a* and *b*) and Figs. 1 and 2; the general structure shown by Pl. II (*b*), the photographs for which and for Plate II (*a*) were taken in 1909, may still be seen in the quarry.

In Pl. II (*a*) a single Grit-filled channel in the limestone is cut across, practically at right angles to its trend, by the quarry-face; it is 22 feet deep from the base of the Trias, which rests at both sides on the enclosing limestone, to the bottom (marked by a hammer). The dark material above the broken white line is the Trias; its base, though somewhat uneven, crosses from limestone to Grit without any indication of post-Triassic subsidence. The sides of the channel are shown by a continuous white line. The lower two-thirds of the infilling is fine sandstone, in which bedding-planes are obscure except for some along the bottom, parallel to the broad base of the channel. The sandstone is hard, and unbroken by any subsidence since its consolidation. That its filling the channel dates from the Carboniferous is shown by its containing (at the point

¹ In the Geol. Surv. Coll. at Jermyn Street Museum (Regd. No. E.D. 1791).

marked with a black cross) the large stem of *Lepidophloios*? previously mentioned, the leaf-cushions impressing sandstone similar to, and continuous with, the rest of the rock. In the upper third, the thin sandstones and shales have a steady catenary bedding.

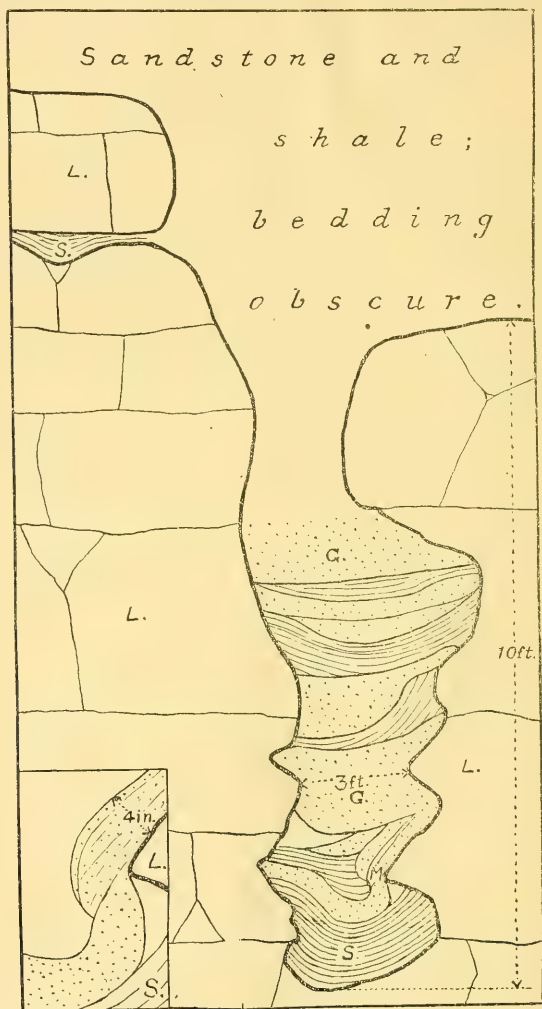


FIG. 1.—Diagrammatic sketch of a "pipe" in Carboniferous Limestone (L.), filled with sandstones (G.) and shales (S.). (Inset: detail of lamination in sandstone at M.)

The sides of the channel overhang in places, to a marked extent between the figure and the pick. The surrounding limestone, which occurs as almost horizontal beds—a well-marked layer runs along

below the hammer—contains cavities filled with sandstone, or with sandstone and shale. The latter are similar to, but generally smaller than, that shown in Fig. 2. * One near the shovel has been partly picked out with a white line, but the others do not contrast sufficiently with the enclosing limestone to show up in the photograph. Those filled with sandstone alone are difficult enough to delimit on the ground, as the sandstone has a calcareous cement and is firmly welded to the similarly-weathering limestone that encloses it.

Pl. II (*b*) shows a wider extent of the junction of limestone and Grit, the distance from *A* to *E* being 50–60 yards. The base of the Trias (above and to the left of *B*) is shown by a broken black line. The surface of separation of Grit from limestone is marked, by continuous black lines, only where it is clear in the photograph; between the Grit-filled hollows *C* and *E* it was too complicated to be traced readily. For one thing undisturbed limestone has an awkward trick of poking up amid Grit where least expected. The masses in this position may be presumed to be remnants, isolated laterally by confluent Grit-filled hollows, somewhat similar to the top (*B*) of the limestone between the Grit-filled hollows *A* and *C*, which appears to be surrounded by Grit. Doubtless *B* is, or has been, continuous with the limestone below, and the strip of Grit, apparently below it, is either banked against it or fills a channel crossing it. In some cases, however, as in that of undisturbed limestone at *D*, the boundary with the Grit is most irregular, and no adjacent limestone is exposed.

Conversely, as in the limestone enclosing the channel shown in Pl. I (*a*), Grit appears repeatedly in the limestone below the black line, filling vertical “pipes” and irregular cavities. Generally the communicating passage with the main mass of Grit above is not to be seen, but one definite “pipe”, shown in Fig. 1, is continuous therewith. The overlying Grit is seen on the right, and the bottom of the “pipe” is 10 feet below. The contents (sandstone and shale) have evidently remained undisturbed since their first introduction, as sand and mud, and consolidation. The 4 in. sandstone, shown in detail at the bottom of the figure, curves sharply in conformity with the steeply-sloping surface of the limestone-wall and with the shale filling the bottom of the “pipe”, but is now quite hard.

A large, irregular cavity (Fig. 2), 6 yards in length, filled with sandstone and shale, of which the form was more than usually clear, was seen in the quarry-face opposite that shown in Pl. II (*b*). The sandstone occurs partly as a horizontal wedge, about 6 feet thick at the larger end, partly as thin laminæ interbedded with the shales. At one place small carbon-lined moulds suggest that plant-fragments have been washed in with the sand, now represented by the sandstone. On the right the cavity is prolonged vertically downward as a funnel-shaped shale-filled “pipe”. This was cleared for 3½ feet below the sandstone-wedge without being bottomed.

The chief questions that arise are:—

1. Were the hollows in the limestone formed before or after the deposition of the beds spoken of as Millstone Grit?

2. What is the age of the so-called Millstone Grit?

1. The catenary bedding of the sandstones shown in Pl. II (a) suggests at first sight subsidence into a local hollow formed after their deposition. The remainder of the evidence is, however, overwhelmingly against this conclusion. The sandstones have been deposited as sand in their present position, and have not been disturbed since consolidation. They contrast strongly with the debris of Millstone Grit filling swallow-holes, both recent and pre-Glacial, in the Carboniferous Limestone at various places in South

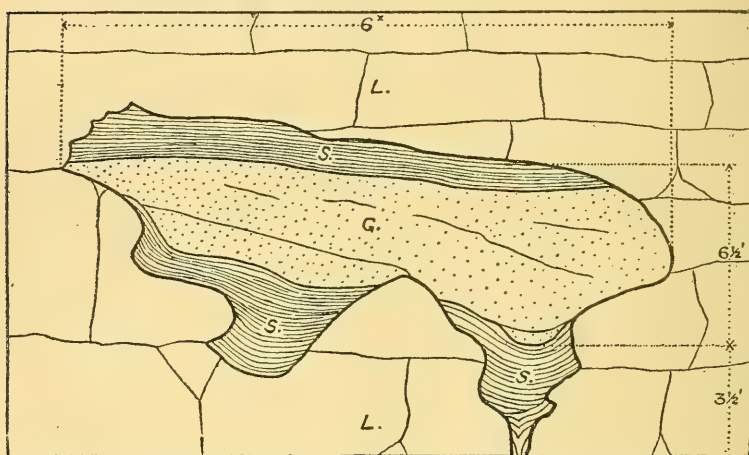


FIG. 2.—Diagrammatic sketch of a cavity in Carboniferous Limestone (L.), filled with sandstone (G.) and shales (S.).

Wales; in these the sandstones and shales are broken, or even thoroughly shattered, and jumbled together. The evidence that the Ifton sandstones have not been disturbed since consolidation needs to be unearthed in the field to be fully appreciated. It consists partly in the unbroken character of the hard beds, straight and curved alike, which are too brittle to bend, partly in the fact that the wedge-like form of some and the minor details of the lamination of others (as at *M*, Fig. 1) have been obviously determined by adjacent limestone-surfaces, and partly in the firm welding of some to the enclosing limestone.

2. The *Lepidophloios*? was certainly deposited contemporaneously with the enclosing sandstone and was not part of a derived fragment. But this genus merely shows that the beds are Carboniferous. The lithological and stratigraphical evidence, however, is fairly conclusive. The choice of horizon lies between some part of the

Upper Avonian, the Basal Grit of the Millstone Grit, and some part of the Coal Measures.

As previously mentioned sandstones are present to a greater or less extent in the Upper Avonian in the adjacent Bristol and Forest of Dean districts, and in the eastern part of the South Wales basin also. But these sandstones are invariably conformable with the underlying beds, and cannot, therefore, be compared with the Ifton sandstones.

It is harder to choose between the Basal Grit and the Coal Measures. Both formations have been proved to rest unconformably on the Carboniferous Limestone in adjacent regions: in the South Wales basin, about 14 miles to the west, in the case of the Basal Grit; and in the Forest of Dean,¹ at the same distance to the north-east, in that of the Coal Measures. It is probable, too, that the unconformities on both horizons have been preceded by "piping" of the Carboniferous Limestone. This has certainly happened prior to the deposition of the Basal Grit, and appears also, from Dr. Sibly's² description, to have preceded the formation of the Coal Measures of the Forest of Dean.

In support of a Coal Measure age we have the presence of Coal Measures close by, Pennant Sandstone and coals having been proved³ in the Severn Tunnel near Southbrook, $2\frac{1}{2}$ miles east of Ifton. On the other hand, the Ifton sandstones resemble neither the Pennant, nor the Trenchard Upper Coal Measures, described by Sibly, that form the base of the Coal Measures in much of the Forest of Dean. It is possible, of course, that what have been spoken of as two unconformities are really but one, accompanied by persistent overlap of the overlying basal beds between South Wales and the Forest of Dean. On this hypothesis the Forest of Dean would represent part of the margin of the South Wales basin, and the Ifton sandstones might be correlative with neither the Basal Grit, deposited, presumably soon after the uplift and subsequent subsidence, in the interior part of the basin, nor with the Upper Coal Measures, laid down much later in the Forest of Dean. Simplicity has its charms, and the postulation of breaks in "conformable" series should be regarded as an unpleasant duty rather than a light mental exercise. But in this case it happens that a break between Middle and higher Coal Measures has been proved in Wyre Forest at no great distance north of the Forest of Dean. The hypothesis of a persistent overlap between South Wales and the Forest of Dean therefore does not help us. As a fact the Ifton sandstones so closely resemble the Basal Grit of South Wales that, in default of conclusive evidence to the contrary, we must refer them to that horizon and suppose, as a corollary, that there has been no overlap

¹ T. F. Sibly, *GEOL. MAG.*, 1912, p. 420.

² *GEOL. MAG.*, 1918, p. 26.

³ Charles Richardson, *Proc. Bristol Nat. Soc.*, ser. III, vol. v, 1887, p. 49, section.

among the beds that have immediately overlain the Carboniferous Limestone for at least a dozen miles east of the main outcrop in South Wales. A determination of the age of the Coal Measures at the Severn Tunnel, which are exposed, so far as known, only in the half-tide rock called Lady Bench, would be both interesting and important; their relationship to the so-called Millstone Grit that was proved below in the Tunnel works we cannot hope to learn. This Millstone Grit appears, from the descriptions and section made by the first engineer¹ of the tunnel and by one of his assistants,² to have "piped" the underlying Carboniferous Limestone as do the Ifton sandstones.

A minor point is the question whether any of the Grit now present in Ifton quarry has been deposited in the light of day or whether it has all been laid down in cavities, the limestone-roof of which has been removed by the pre-Triassic denudation. The fact that some of the channels, such as that in Pl. II (a) and A in Pl. II (b), which, from their relative positions in the quarry, are probably continuous one with the other, are *large and widen upward* may count for little, but the persistence of the Grit beneath the Trias for a distance of 50 yards, more or less at right angles to the trend of these channels, suggests deposition in the open.

CONCLUSIONS

The Carboniferous Limestone was eroded subærially prior to the deposition of the Ifton sandstones, the *Dibunophyllum* Zone presumably being removed and the *Seminula* Zone below irregularly worn into deep channels with steep, even overhanging sides, into vertical "pipes" descending an unknown depth into the limestone, and into every conceivable intermediate form of cavern and passage.

The sandstones and shales, with rare plant-remains, that were then deposited in and on the limestone were contemporaneous with the Basal Millstone Grit.

My cordial thanks are due to the Ifton Limestone Company, Ltd., for their courtesy in readily permitting me to examine the quarry and to publish this account, to the Director of H.M. Geological Survey for the photographs for the plates, and to Messrs. T. C. Hall and G. Maunsell for help in the field.

¹ Charles Richardson, *op. cit.*

² E. D. Jones, *Proc. Geol. Assoc.*, vol. vii, 1881-2, p. 339.

Correlation between the Meadfoot Beds of Devonshire and the Siegenian of the Ardennes (Lower Devonian).

By ETIENNE ASSELBERGHS, D.-en-Sc. (Louvain), of the Geological Survey of Belgium.

SECT. 1.

IN a study of the Lower Devonian of the "Bassin de l'Eifel"¹ the present writer established the following sequence in the Siegenian Beds (= Siegenerstufe of the Rhine) of the southern part of the Ardennes:—

Upper Siegenian or Hunsrückian.	Upper: dark blue shales and slates. Lower: quartzophyllades, often calcareous (lenticular or Bouillon), sandstones, and shales. Very fossiliferous.
Lower Siegenian or Taunusian.	Dark blue slates and shales interbedded with quartzite.

The Lower Hunsrückian has yielded an important fauna,² and the most characteristic species are: *Proschizophoria* [Orthis] *personata* (Zeiler) Kayser *em.*, *Stropheodonta Murchisoni* Archiac and Verneuil, *S. Sedgwicki* A. and V., *S. gigas* McCoy, *S. herculea* Drevermann, *Schuchertella ingens* Drevermann, *Spirifer hystericus* Schlottheim, *S. excavatus* Kayser, *S. primaevus* Steininger, *S. solitarius* Krantz, *Rhynchonella papilio* Krantz, *R. Dannenbergi* Kayser, *Rhenorensellaeria crassica* Koch, *R. strigiceps* Roemer, *Uncinulus frontecostatus* Drevermann, *Cornellites Paillettei* Verneuil and Barrande, *Grammysia taunica* Kayser, and *Cryphaeus Drevermanni* Richter.

The purpose of this note is to show that the same succession occurs in Cornwall and South Devonshire.

SECT. 2.

The Lower Devonian of Cornwall is a quartzoschistose complex affected by numerous plications and dislocated by a great number of faults. Therefore the geologists who tried to establish a stratigraphical succession met with difficulties far exceeding those experienced by workers in the Ardennes. Nevertheless, they distinguished three formations known, in descending order, as the Staddon Grits, the Meadfoot Beds, and the Dartmouth Slates.

The Dartmouth Slates correspond to the Gedinnian of the Ardennes. On the other hand, the Staddon Grits are succeeded by

¹ Le Dévonien inférieur du Bassin de l'Eifel et de l'Anticlinal de Givonne dans la Région sud-est de l'Ardenne Belge. Aperçu général sur le Bassin de l'Eifel entre la Meuse et la Kyll. *Mém. Inst. géol. de l'Université de Louvain*, vol. i, 1913, pp. 1-175, pls. i-iii.

² The fauna of this horizon of the southern border of the Bassin de Dinant has been made known by Béclard (*Bull. Soc. belge de Géol.*, vol. i, 1887, pp. 60-96) and by Maillieux (*ibid.*, vol. xxiv, 1910, *Mém.*, pp. 189-220). I have given a critical list of the species collected in the Bassin de l'Eifel (*loc. cit.*, pp. 85-132). This list has been added to by Maillieux (*Bull. Soc. belge de Géol.*, vol. xxviii, 1914, *Proc. verb.*, pp. 77-9).

shales and limestones with *Calceola sandalina* Lamarck. It follows, therefore, that the Meadfoot Beds and the Staddon Grits are the equivalent of the Siegenian, Emsian, and the beds with *Spirifer cultrijugatus* Roemer. The correlation therefore stands thus :—

ARDENNES AND RHINE.	SOUTH DEVONSHIRE.
Couvinian : Shales and limestones with <i>Calceola sandalina</i> .	
Beds with <i>Spirifer cultrijugatus</i>	} Staddon Grits and Meadfoot Beds.
Emsian or Coblenzschichten	
Siegenian or Siegenerstufe.	
Gedinnian (Upper).	
	Dartmouth Slates.

The comparative study of the Devonian Beds of the two countries has been left in this summary state. I will try to go a little further by recalling what is known concerning the Meadfoot Group.

SECT. 3.

Ussher¹ has shown that the Meadfoot Group of Cornwall can be divided into three horizons, of which the two oldest have been traced throughout the county and also in Torbay. The following is the succession of strata in descending order :—

- c. Grey slates with occasional beds and seams of grit (thick beds of grit are seen near Plymouth).
- b. Very fossiliferous shales, slates, and grits; calcareous bands with corals and crinoids (lenticular limestones).
- a. Dark grey slates with hard grit and quartzite beds.

The middle horizon is easily recognizable by its calcareous bands and fossiliferous beds—the latter have yielded a very rich fauna—and can be traced through the numerous folds.

The first fossils were found at Looe and were described by Davidson.² E. Kayser has drawn attention to the affinities of this fauna with that of the Taunusquartzit of the Rhine.³ More recently Drevermann showed that the fossils of Looe exist in the Siegenerstufe of Seifen.⁴ In 1915 I had the opportunity of seeing the fossils from Looe in the British Museum (Natural History), and I was impressed by the great affinities of the fauna of Looe with that of the Lower Hunsrückian of the Bassin de l'Eifel. All the brachiopods from Looe occur in the Ardennes. The following table gives Davidson's list, beside my identifications :—

<i>Athyris</i> sp. ? pl. iv, fig. 4.	<i>Athyris avirostris</i> Krantz.
<i>Spirifera primaeva</i> Steininger ? ?	<i>Spirifer primaevus</i> Steininger.
pl. viii, figs. 1-3.	
<i>Spirifera</i> sp. ? pl. iv, fig. 33.	<i>Athyris avirostris</i> Krantz.
<i>Spiriferina cristata</i> var. <i>octoplicata</i> ? pl. vi, figs. 11-13.	<i>Spirifer excavatus</i> Kayser.

¹ *Mem. Geol. Surv. England and Wales*: Explanation of Sheet 350 (1903), 348 (1907), 347 (1909), 349 (1912). *Proc. Geol. Assoc.*, vol. xx, 1907, pp. 78-93. "Geology in the Field": *Jubilee Vol. Geol. Assoc.*, 1910, pp. 859, et seq.

² Davidson, "A Monograph of the British Fossil Brachiopoda": vol. iii, pp. 126-7. *Mem. Pal. Soc.*, 1864-71.

³ *Jahrb. der. k. Preuss. Geol. Land.*, 1882, pp. 128-31.

⁴ *Palaeontographica*, vol. iv, 1904, pp. 229-88.

Atrypa reticularis Linné.

Rhynchonella Pengelliana Davidson, pl. xii, figs. 8, 9.

Rhynchonella sp.

Streptorhynchus gigas McCoy.

Pl. xvi, figs. 2, 3.

fig. 4.

Streptorhynchus vel *Leptaena* sp.?

(*Leptaena*? *Looiensis* Davidson), pl. xviii, figs. 13, 14.

Orthis (vel *Leptaena*) *laticosta* Conrad.

Orthis hipparionyx Vanuxem?

Pl. xvii, fig. 8, 9, 12.

fig. 10.

fig. 11.

Rhynchonella papilio Krantz.

Stropheodonta gigas McCoy.

Orthothes ingens Drevermann.

Stropheodonta Sedgwicki Archaic and Verneuil.

Proschizophoria personata (Zeiler).

P. provulvaria? Maurer.

Athyris avirostris Krantz.

Later, other fossiliferous localities were discovered. Several lists of fossils have been published, but a great number of the identifications, based only on the already old descriptions of Phillips and Davidson, are doubtful. Thus, for instance, in the same list we find *Spirifer speciosus* and *S. primaevus* recorded together.¹ The identifications which seem to have been made with most care are those of Green² (1904–1906). From his lists we can add the following species to the above table: *Dalmanella circularis*, *Proschizophoria provulvaria*, *Stropheodonta Murchisoni*, *Leptostrophia explanata*, *Rhenorensella strigiceps*, *Camarotoechia daleidensis*, *Spirifer hystericus*, and *Phacops Ferdinandi*. All these species are found in the Ardennes. Corals and crinoids are abundant. From this list we may conclude that the fauna of the fossiliferous horizon of the Meadfoot Group and that of the Lower Hunsrückian of the Ardennes are identical.³

Moreover, the fossiliferous beds of Devonshire consist of quartzschistose rocks and sometimes calcareous rocks just as in the Ardennes, and they lie between two schistose horizons, of which the older contains intercalations of sandstone and quartzite. The same succession occurs in the Ardennes. Finally, both the Meadfoot Beds and the Siegenian rest on the purple and green shales of the Upper Gedinnian.⁴

¹ Hamling, GEOL. MAG., 1909, pp. 133–4.

² GEOL. MAG., 1904, p. 406; 1906, pp. 34–5.

³ This opinion has been confirmed by a recent rapid examination of the specimens from Looe and Fowey in the Sedgwick Museum, Cambridge, and the Geological Survey Collection at Jermyn Street, London.

⁴ This is not quite true of the western part of the Bassin de l'Eifel, where the formations are much thicker. There exist between the red and green shales of the Gedinnian and the shales and quartzite of the Taunusian, two horizons: one consists of greenish shales (*Schistes de St. Hubert*) and the other of quartzophyllades and shales (Lower Taunusian). These two horizons disappear towards the east and in the neighbourhood of Laroché, at the south-western corner of the "Massif de Stavelot", the red and green shales of the Gedinnian are succeeded immediately by the slates and quartzites of the Taunusian.

I therefore propose the following correlation :—

MEADFOOT GROUP.	SIEGENIAN.
c. Grey slates with bands, and locally thick beds, of grit.	c. <i>Hunsrückien supérieur</i> : phyllades bleu foncé de Neufchâteau (intercalations gréseuses dans le Grand Duché de Luxembourg).
b. Fossiliferous beds of Looe: slates and grits, calcareous shales, and lenticular masses of dark-grey limestone.	b. <i>Hunsrückien inférieur</i> : quartzophyllades fossilifères, souvent calcareux; lentilles calcaireuses de Bouillon.
a. Dark grey slates with hard grit and quartzite beds.	a. <i>Taunusien</i> : phyllades bleu foncé avec intercalations de grès quartzite gris bleuâtre.

SECT. 4.

It follows logically from the above correlation that the Staddon Grits, which lie between the beds with *Calceola sandalina* and the Meadfoot Beds, correspond to the Emsian Group and the *Cultrijugatus* Beds of the Ardennes.

The stratigraphical succession in the Staddon Grits is not known in detail as yet, but I do not doubt that the principal fossiliferous horizons which characterize these beds in the Ardennes will be found in Devonshire by detailed research. These horizons are, in ascending order, the beds with *Spirifer hercyniae* and *Tropidoleptus rhenanus*, the beds with *Sp. arduennensis* and the beds with *Sp. cultrijugatus*. In fact, some localities in the neighbourhood of Torquay have already yielded *Tropidoleptus rhenanus*; others *Sp. cultrijugatus*.¹

From the foregoing remarks the correlation of the Lower Devonian and the Lower Middle Devonian of South Devonshire and the South of the Ardennes stands thus :—

SOUTH OF DEVONSHIRE.	ARDENNES AND RHINE.
Limestones and slates with <i>Calceola sandalina</i> .	Assise à <i>Calceola sandalina</i> } Couvinien.
Staddon Grits.	{ Assise à <i>Sp. cultrijugatus</i> Assise à <i>Sp. arduennensis</i> Assise à <i>Sp. hercyniae</i> et <i>Tropidoleptus rhenanus</i> } Emsien ou Coblenzstufe.
Meadfoot Beds. { Grey slates. Fossiliferous Looe Beds. Slates with quartzite.	{ Hunsrückien supérieur Hunsrückien inférieur Taunusien } Siegenien ou Siegenerstufe.
Dartmouth Slates.	Schistes bigarrés du Gedinnien.

In the correlation table given by Dr. J. W. Evans in 1917,² it will be noticed that the Staddon Grits are made to correspond with the

¹ Ussher, "The Geology of the Country around Torquay" (Explanation of Sheet 350): *Mem. Geol. Surv.*, 1903.

² Evans, "Devonian (Sedimentary Rocks) of Great Britain": *Handb. d. Regionale Geol.*, vol. iii, pt. i; *The British Isles*, 1917, pp. 134-5.

Cultrijugatus Beds and the Meadfoot Group with the Emsian and Siegenian. I am unable to find any evidence in favour of this parallelism in the detailed studies of Mr. W. A. E. Ussher on the Devonshire rocks. On the contrary, it seems foolish to correlate the whole of the Staddon Grits with the *Cultrijugatus* Beds, when certain bands of the former have yielded *Tropidoleptus rhenanus*.

SECT. 5.

Finally, a few words may be said about the Devonian rocks of North Devon. The stratigraphical succession is less known than in the South; nevertheless, it seems very doubtful if it will ever be possible to distinguish the three horizons of the Siegenian in the Lynton Beds which correspond to the Meadfoot Beds, according to Ussher¹ and Evans.² In fact, the Devonian of North Devon, where the quartzschistose facies characterizes not only the Lower Devonian but affects also the Lower Middle Devonian (Couvinian) and even the lowest beds of the Givetian, would have to be compared with the Northern border of the "Bassin de Dinant" or with the "Massif de la Vesdre". In the latter region the Devonian rocks below the Givetian Limestone consist of an alternation of purple-red shales and greenish arenaceous bands; conglomerates occur at several horizons.³ More especially the Siegenian consists in the upper part of purple-red shales and greywacke with pink sandstones, and in the lower part of grey and bluish sandstones and quartzites with dark-blue slates. *Haliserites Decheslianus* and bone-beds of Ostracoderms (*Pteraspis*) are frequent in the Taunusian or Lower Siegenian.⁴ In the same way the Lynton Beds of Devon contain beds with *Pteraspis*. In the present state of our knowledge, however, it is not possible to establish a more detailed correlation between the Lower Devonian of North Devon and the Ardennes.

SECT. 6.

In 1912 I showed that the Siegenian presents the same succession in the South of the Ardennes—southern border of the Bassin de Dinant, Anticlinal de Bastogne, Bassin de Houffalize, Bassin de l'Eifel, Anticlinal de Givonne—and in the Siegerland. It may now be concluded that a similar succession occurs also in Cornwall and South Devonshire.

[Note: In accordance with modern usage Dr. Asselberghs adopts Siegenian and Emsian in place of the much misused term Coblentzian. The necessity for discarding the latter is shown by Maillieux, *Bull. Soc. belge de Géol.*, vol. xxx, 1920.—L. D. Stamp.]

¹ Ussher, "Geology in the Field": *Jubilee Vol. Geol. Assoc.*, 1910, pp. 864, et seq.

² Evans, *Geol. Mag.*, 1919, pp. 547-9.

³ A section through the Massif de la Vesdre has been given recently in the *Bull. Soc. belge de Géol.*, vol. xxix, 1919, pp. 220-31.

⁴ Asselberghs, "Découverte de bone-beds à Ostracodermes dans le Taunusien, à l'est de la Meuse": *Bull. Soc. belge de Géol.*, vol. xxx, 1920.

The Marginal Features of a Basic Dyke at Peldar Tor, Charnwood Forest.

By W. ALFRED RICHARDSON, M.Sc., B.Sc.(Eng.), F.G.S.

IN the most westerly working of Peldar Tor Quarry, in the north-west district of Charnwood Forest, a basic dyke is intruded into the porphyroid. Professor T. G. Bonney¹ briefly described the dyke in 1915. The intrusion shows a remarkable laminated margin, and the present paper is chiefly directed to a consideration of this feature.

I. CHEMICAL COMPOSITION.

The Porphyroid.—T. G. Bonney and E. Hill determined this rock as a dacite. In Table I are collected all available analyses, and to these I have added another from a specimen chosen as typical of the rock in the neighbourhood of the dyke.

It will be seen that these analyses differ somewhat. This is doubtless due to variation of the specimens selected as regards quartz phenocrysts. For, while the rock exposed in the quarries is uniform when considered as a whole, yet the crowding of the quartz phenocrysts may fluctuate in different specimens. The analysis No. I from the Peldar Tor Quarry probably represents a specimen rather poorer in quartz than the general body of the rock, and the analyses Nos. II to IV are more typical.

TABLE No. 1.

	I	II	III	IV
SiO ₂	61·28	65·14	67·96	66·32
Al ₂ O ₃	16·11	16·13	14·87	13·69
Fe ₂ O ₃	7·22	5·37	10·60	8·54
MgO	4·19	2·19	1·10	2·09
CaO	6·33	5·16	1·69	2·59
Na ₂ O	0·99	1·56	5·07	4·50
K ₂ O	3·84	1·75	tr.	
P ₂ O ₅	—	—	tr.	0·75
MnO	tr.	—	tr.	n.d.
Ignition	—	2·14	—	2·05
Total	99·96	99·44	101·29	100·53

- I. "Porphyroide," Peldar Tor Quarry, Whitwick (by the courtesy of Mr. J. H. Robinson).
- II. Do., Forest Rock Quarry, Whitwick (by the courtesy of Mr. J. W. Berrington).
- III. Do., Peldar Tor (T. G. Bonney, *Quart. Journ. Geol. Soc.*, vol. xxxviii, 1882, p. 199; analyst, E. Berry).
- IV. Do., Peldar Tor Quarry, most westerly sinking near Greenstone Dyke.

A comparison of these analyses with the mean given by Daly² indicates that for dacites they are high in iron and low in alkalis.

¹ Bonney, *GEOL. MAG.*, 1915, p. 548.

² Daly, *Igneous Rocks*, New York, 1914, p. 25.

Nor do they show very close agreement with respect to those constituents with any individual dacite, the analysis of which is available. The rock would seem to be a rather basic member of the group. There is, however, a tonalite from Lake Avio, Tyrol,¹ whose analysis compares much more closely with that of the porphyroid.

The Dyke.—The dyke shows a chilled marginal phase and a crystalline centre. I give in Table II analyses from the best obtainable specimens of each phase. It will be seen that they represent, as Professor Bonney suggested, a dolerite. The analysis from the centre compares with the quartz dolerite of the Whin Sill, quoted in column III.

TABLE No. II.

	I	II	III
SiO ₂ . . .	52·21	50·43	51·22
Al ₂ O ₃ . . .	16·09	14·44	14·06
Fe ₂ O ₃ . . .	13·00	12·80	4·32
FeO . . .	n.d.	n.d.	8·73
MgO . . .	4·15	4·35	4·42
CaO . . .	5·44	11·12	8·33
Na ₂ O)	3·09	1·04	1·25
K ₂ O)			2·55
P ₂ O ₅ . . .	0·40	0·45	—
MnO . . .	n.d.	n.d.	—
TiO ₂ . . .	n.d.	n.d.	2·42
Ignition, etc.	5·00	5·00	2·37
Total . . .	99·38	99·63	99·67
Sp. Gr.	2·77	2·81	

I. Greenstone Dyke, Peldar Tor Quarry, Whitwick. Marginal Phase.

II. Centre.

III. Quartz Dolerite, Whin Sill, Cauldron Snout. (J. J. H. Teall.)

It will be noticed that the marginal phase is rather more acid and of lower specific gravity than the centre of the intrusion. This may possibly be due to a slight amount of marginal assimilation, for microscopic slices at the contacts show portions of the porphyroid partially absorbed. The specimen analysed was obtained quite close to one of the contacts.

II. PETROGRAPHY.

The Porphyroid.—Little need be said about this rock, since it has been minutely described by Professor Bonney.² The phenocrysts consist of corroded and fractured quartz, plagioclase, and aggregates of fine epidote grains, forming pseudomorphs after a ferromagnesian mineral. One of these preserves an almost perfect octagonal cross-section with prism faces nearly at right angles, indicating that the

¹ Iddings, *Igneous Rocks*, vol. ii, New York, 1913, p. 142, No. 2.

² Bonney & Hill, *Quart. Journ. Geol. Soc.*, vol. xxxvi, p. 342, 1880.

original mineral was pyroxene. The groundmass contains a second generation of feldspars, rather more acid than the phenocrysts, but is otherwise largely cryptocrystalline.

The Greenstone.—Under the microscope a specimen from the dyke centre is seen to be holocrystalline and of medium grain. It is completely altered. With the exception of quartz none of the original minerals remain. The rock now consists mainly of quartz, chlorite, kaolinized pseudomorphs after feldspar, calcite, and iron oxide. The structure is best made out by reflected light, when felted patches of lath-shaped feldspars are seen to be surrounded by dark chlorite, showing that the original structure was ophitic or sub-ophitic.

The chlorite is in ragged crystals and forms a kind of groundmass to the slide. It shows strong pleochroism and numerous inclusions of magnetite, and has the velvet-brown ultra-interference tints of penninite.

The feldspar pseudomorphs are chiefly kaolin, sometimes with a grain or so of epidote here and there ; but calcite replacements are not uncommon.

The iron-ores are all changed to hæmatite and sometimes to leucoxene.

Quartz is the most interesting mineral. There is a good deal more of it than the analyses would lead one to expect. Little triangular fragments, similar to those seen in the Whin Sill, are clearly interstitial. Others take on the shape of feldspar laths, and show a central plane of division corresponding to a Carlsbad twin-plane. The two halves extinguish differently. These larger quartz crystals may include calcite and chlorite flakes. Much of this quartz is doubtless secondary. Strain shadows are shown, but not so marked as in the quartz of the porphyroid.

In one slide only there occur some irregularly oval rings of magnetite, enclosing carbonates very suggestive of pseudomorphs after olivine. The occurrence of these pseudomorphs is another reason for considering that the quantity of original quartz was probably small.

It would thus seem certain that the rock forming the centre of the dyke was originally an ophitic dolerite, and possibly a quartz-dolerite.

The marginal phase is very fine-grained. Many of the specimens obtainable are badly weathered and reveal little under the microscope. The dyke has again been quarried more recently and better marginal material has been made available. A slice cut from one of these specimens contains minute feldspar laths, the larger of which are simply twinned. They appear to be oligoclase. The groundmass has a general greenish tinge and is cryptocrystalline. It is quite indeterminate, and was doubtless originally glassy.

The Contact.—Slides cut at the junction show that the contact is marked by a film of iron oxide, *aa*, Fig. 1

The dyke-rock *b* has the characteristics already described for the marginal phase, but the felspar laths show fluxion arrangement parallel to the line of contact.

The porphyroid at the contact has in hand-specimens quite a different appearance to the normal rock. In colour it is generally lighter, greenish, and blotchy. The normal dark-coloured rock can, however, be found attached to fresher portions of the dyke. I think that Professor Bonney is correct in considering these colour variations in the porphyroid as due to weathering, for here the two rocks have often parted along the contact line, and so afforded a passage for water.

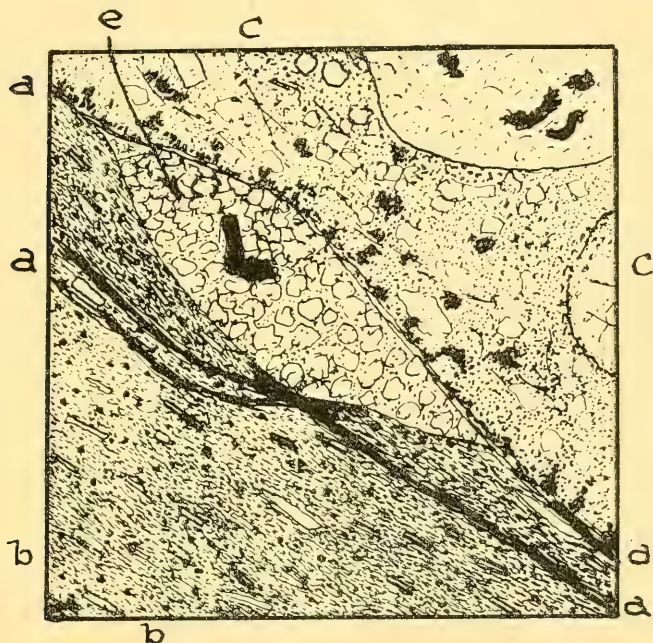


FIG. 1.—Junction of Peldar Tor porphyroid (*c*) and dolerite dyke (*b*). $\times 54$.

Under the microscope the porphyroid, *c*, Fig. 1, has the same general appearance as in the normal rock. There is, however, a marked absence both of traces of ferromagnesian minerals and epidote. Instead there is a large amount of indeterminate green material in the groundmass. The felspars are sometimes distinctly resorbed, and the groundmass near the contact has recrystallized. It then consists of rounded grains of what I take to be felspar set in a felted network of the greenish material already mentioned. Small lenticular patches, *e*, Fig. 1, of clear recrystallized material are caught up along the line of contact, and suggest a certain amount of marginal assimilation by the dyke. Along the contact line in one

slide there is a green mineral, with the refractive index and pleochroism of hornblende, but a low extinction. More exact determination is difficult, for there are only two or three small pieces all similarly orientated. Whether this is the product of contact metamorphism, or is developed by the crushing of the mass, is difficult to say.

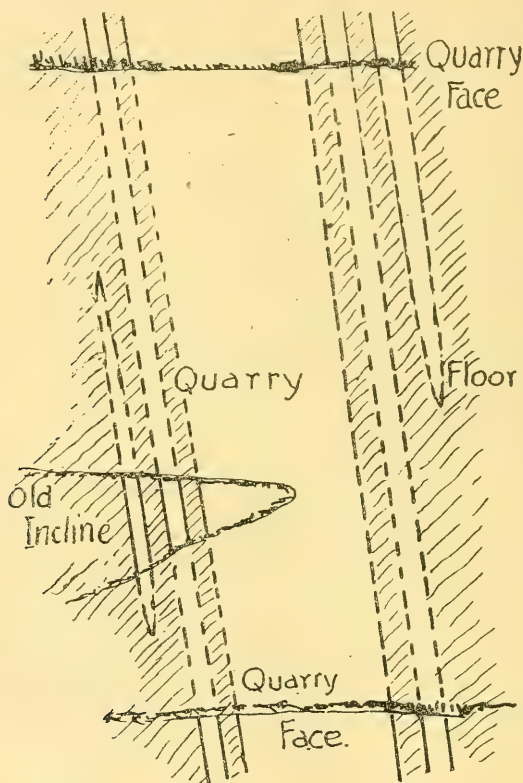


FIG. 2.—Diagrammatic plan of quarry floor showing the form of the laminated marginal sheets. Hatched portion = porphyroid, blank = dolerite dyke.

III. FIELD RELATIONS.

The most interesting features of the dyke are to be found in the field. The dyke trends W.N.W. and hades to the east at about 5 degrees. Its width varies somewhat; but is nowhere less than 12 feet.

Professor Bonney thinks that it has suffered more than the porphyroid from shearing. Specimens from the margin do cleave much more readily than the latter rock, but this is doubtless due in part to the fluxion banding already mentioned. The dyke at the

centre is much less affected than the margin by cleavage, and its quartz in thin section has no very prominent strain phenomena.

The most remarkable feature is the presence of laminated margins (Fig 3). They occur at both sides of the dyke. At first sight they resemble columnar basalt, or certain shearing effects. They really

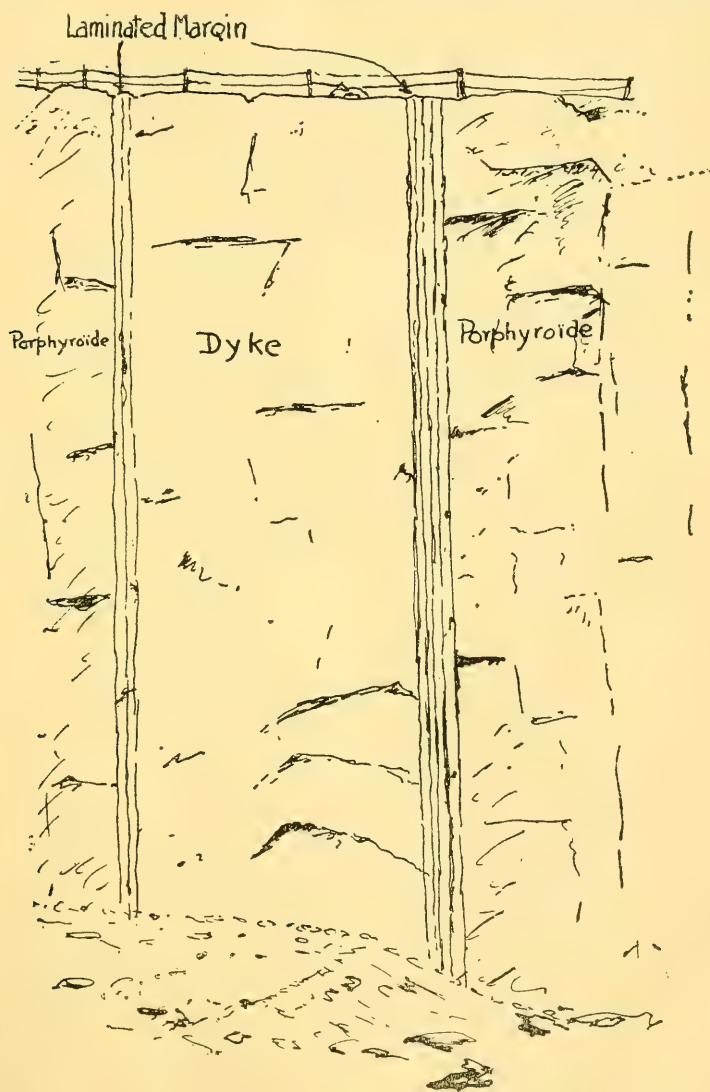


FIG. 3.—Peldar Tor Quarry. Exposure of dolerite dyke showing marginal lamination. View looking north.

consist of alternating sheets of country rock and dyke. These sheets are each about 9 inches thick, and vary in number from two to four. The dyke material of these sheets is chilled, and this chilled phase also extends not less than 2 feet from the main dyke margin.

It was not found practicable to trace the dyke across the floor of the quarry. In 1914, however, an old tramway incline, since quarried away, exposed a portion of the dyke, and was situated between the two exposures on the quarry face. By means of this exposure the reconstruction of the course of the dyke across the floor given in Fig. 2 was made. This sketch is not drawn to scale, and the marginal features are exaggerated in size to show their character. It will be seen that the sheets of dyke material fill cracks of lenticular cross-section in the wall. These cracks die out and may be replaced by others along the course of the dyke.

To the north the dyke cannot be traced, but it does not enter the Trias. Although nothing can be seen of it at present, it has been followed for a short distance southwards.

IV. THE AGE OF THE DYKE.

The dyke, as just mentioned, does not enter the Keuper marl, and is therefore pre-Triassic.

Although in composition and probable mineralogical character it strongly resembles certain Carboniferous dolerites (a few of which are to be found in Midland Coal-measures), it is much more altered than the Carboniferous intrusions. Moreover, it has shared the cleavage of the surrounding rocks, and must be considered as belonging to the pre-Cambrian suite. It should be noted, however, that the well-developed chilled marginal phase points to the country rock being quite cold at the time of the dyke intrusion.

V. THE ORIGIN OF THE MARGINAL LAMINATION.

The dyke occurs to the west of the main Charnian anticlinal axis, and has the hade and direction of the chief faults of the district. There is no evidence of movement, and the included sheets of porphyroid show no signs of shearing or brecciation.

There are three possible explanations of the phenomenon.

1. Contraction of the dyke on consolidation may have cracked the sides and provided means of further intrusion. It would seem that several successive contractions were necessary each of the same order of magnitude, and this does not seem reasonable. Moreover, as in the case of certain "multiple" dykes, it might be expected that the junction of the dyke and the country rock would provide the readiest line of fracture.

2. The other cracks may have been formed by a renewal of tension at a later time. Here, again, one would expect the line of junction to be the most likely plane of weakness. Examination in the field and of the slices at the margin suggests, moreover, that the intrusion and consolidation of all the dyke material took place concurrently.

3. Several tension cracks may have opened at one time. During a long experience in testing various kinds of materials by slowly loading them in tension, I only remember two cases where the test piece gave way at more than one surface. Both cases were very brittle cast-iron. On the other hand, if a piece of material in tension be subjected also to a sudden blow, it is very liable to go at more than one plane. This is seen in the sudden tearing of cloth, where in addition to the main tear, several of lenticular shape and parallel to the main tear frequently appear. If the intrusion occurred at a time of anticlinal tension and the molten material below subjected the crust above to a sudden impulse, the rupture, instead of being confined to one plane, would oscillate over a small region, finally causing fracture at a number of closely spaced vertical planes. The main mass of magma rushed up one of these fissures, and at the same time a smaller amount filled the adjoining cracks. The uniform width of the sheets and the length over which they are exposed suggests suddenness of action, for if the process had been prolonged the main dyke might have been expected to transgress from one fissure to another in different parts of its course.

This explanation is of interest in the light of J. Barrell's theory, based on thermodynamic grounds, that dyke injection has often proceeded in a violent and explosive manner.¹

The Contaminated Gabbro of Easter Saphook near Old Meldrum in Aberdeenshire.

By H. H. READ, H.M. Geological Survey, Scotland.

INTRODUCTION.

IN North-East Scotland the igneous rocks have been divided into two series, whose times of intrusion were separated by the movements responsible for the foliation and disposition of the crystalline schists of that area.² With the older series, intruded prior to or during those movements, this paper is not concerned. The younger, or non-foliated, series supplies rock types ranging from peridotite to granite. Gabbro is the chief rock in the large independent basic masses formed by the younger igneous rocks; to the more important of these masses may be given the names of the Huntly, Inch, Boganloch, Haddo, Arnage, Maud, and Belhelvie Masses. For the most part they lie within Sheets 76, 77, 86, and 87 of the 1 inch Geological Survey Map of Scotland.

This paper is concerned with a group of rocks which can be shown to result from the incorporation of sedimentary material in the gabbro magma. Chief amongst the rocks resulting from the mixture

¹ J. Barrell, U.S.A. Geol. Surv., Prof. Paper, No. 57, p. 157, 1907.

² H. H. Read, *Summary of Progress for 1918, 1919*, p. 24. *GEOL. MAG.*, Vol. LVII, 1919, p. 364. *Summary of Progress for 1919, 1920*, p. 23.

is cordierite-norite, but other mixed rock types, of unquestionably similar origin, occur very abundantly in Aberdeenshire and the general group name of *Contaminated Gabbro* has been provisionally adopted for rocks resulting from a gabbro magma contaminated with sedimentary material.

Before 1914 two occurrences of contaminated gabbro had been described, one in France, the other in Minnesota. In 1898-9 an account of the cordierite-norites of Le Pallet, Loire-Inférieure, was given by Lacroix.¹ In 1900 A. N. Winchell² published the results of a very detailed mineralogical and petrographic study of cordierite-norite, quartz-gabbro, and orthoclase-gabbro from Minnesota. Both authors held admixture with sedimentary material to be the cause of these modifications of the normal gabbro magma.

In 1914 W. R. Watt³ described cordierite-norites and associated rocks from Wells Cuternach, near the farm of Drumdelgie, 3 miles west-north-west of Huntly, Aberdeenshire. He said:—

“It appears certain that the rocks of this (Cuternach) type originated from a magma contaminated by the aluminous material of the phyllites.

“It is greatly to be regretted that no clear sections exist to prove in the Huntly occurrence a gradual transition from undoubted igneous rock to undoubted phyllite” (loc. cit. p. 288).

In 1919 the localities of this type of cordierite-norite were vastly increased, contaminated norites being shown to occur over great parts of the Huntly Mass.⁴ Moreover, sections were discovered which showed that there could be no doubt that the formation of cordierite-norites and allied contaminated rocks was due to the incorporation of sedimentary material in the gabbro magma.

A year later the distribution of contaminated gabbros was again widened by their discovery as a marginal modification of the hypersthene-gabbro of the independent Inch Mass near the farm of Easter Saphook, 2½ miles west by north of Old Meldrum.⁵ During this year (1920) in an investigation of the igneous rocks of the Arnage Mass, undertaken during leave from official work, I have found that contaminated norites bulk very much larger than the uncontaminated nuclear norite. It may be said, then, that contaminated gabbros occur, so far as is known at present, in the Huntly, Inch, and Arnage Masses, and there is every possibility that their distribution will be still greater as the remaining younger igneous masses of North-East Scotland come to be studied.

¹ A. Lacroix, “Le Gabbro du Pallet et Ses Modifications”: *Bull. Carte Geol. de la France*, vol. x, 1898-9, pp. 341-96.

² A. N. Winchell, “Mineralogical and Petrographic Study of the Gabbroid Rocks of Minnesota, etc.”: *American Geologist*, vol. xxvi, 1900, p. 294 et seq.

³ W. R. Watt, “Geology of Country around Huntly (Aberdeenshire)”: *Q.J.G.S.*, vol. lxx, 1914, pp. 266-93.

⁴ H. H. Read, *Summary of Progress for 1918, 1919*, pp. 29, 30.

⁵ H. H. Read, *Summary of Progress for 1919, 1920*, p. 26.

CONTAMINATED GABBROS OF EASTER SAPHOOK.

Easter Saphook is situated at the extreme end of the Inch Mass, some $2\frac{1}{2}$ miles west by north from Old Meldrum. The contaminated gabbros outcrop in several small knolls around the copse a few hundred yards south of the farm. Small quarries opened in these knolls provide excellent specimens of the mixed rocks. Just east of this locality various types of sedimentary gneisses are seen near the burn which runs from north to south a few hundred yards east of Easter Saphook. The mixed rocks, therefore, occur at the margin of the igneous mass.

The uncontaminated igneous rock of this part of the Inch Mass is a fairly uniform hypersthene-gabbro.¹ It is a fine-grained greyish rock, weathering into rectangular slabs. In thin slice the texture is seen to be uniformly equigranular. The constituent minerals are labradorite, hypersthene, augite, and magnetite. The feldspar occurs in stout crystals. The two pyroxenes are about equal in amount and are often intergrown. The hypersthene builds vividly pleochroic prismatic grains; the augite forms similarly shaped grains with a well-marked diallagic parting.

Around Easter Saphook, however, the uniformity which elsewhere characterizes the hypersthene-gabbro is lost. Here the rocks become very variable, all degrees of textural and mineralogical variations being seen in the same exposure and often in the same hand-specimen. Hornfelsed sedimentary blocks can be hammered out of the contaminated igneous matrix. It is at once apparent that here are assimilation phenomena similar to those repeatedly observed in the Huntly Mass.

At Easter Saphook the earliest stage in contamination is represented by a hypersthene-gabbro, which, whilst in the main similar to the normal rock of that group, yet shows peculiar features, indicative of its mixed origin. These least modified types are medium-grained greenish rocks, with little of that variability shown by more modified examples of this suite. Their constituent minerals are labradorite, hypersthene, scarcer augite, biotite, quartz, magnetite, and secondary green hornblende. Evidences of modification are provided by:—

(i) The presence and skeletal arrangement of the biotite, which is always near iron-oxide grains.

(ii) The occurrence of scattered areas of quartz, which often forms patches, blebs, and points in the feldspar, and then the two minerals tend to occur in regular granophyric or micropegmatitic intergrowths.

(iii) The purplish grey appearance of the hypersthene.²

(iv) The tendency of the hypersthene to form a collection of grains rather than homogeneous crystal plates. There is a rude orientation of feldspar and hypersthene, pointing to movement during consolidation.

¹ *Ibid.*, p. 24.

² W. R. Watt, *loc. cit.*, pp. 282, 286.

Further stages show increasing divergence from the igneous rock until the main characters of the mixture become dependent more upon the sedimentary than upon the igneous components. This divergence is exemplified firstly by a group containing much quartz, and secondly by a group containing cordierite.

In the first branch the components are andesine, quartz, hypersthene, biotite, garnet, magnetite, and zircon. Chlorite and hornblende are of late secondary formation. The felspar forms euhedral crystals; quartz is abundant; hypersthene commonly occurs in small grains vividly pleochroic in red, yellow, and blue-green tints. Yellow to red biotite builds large plates usually with the skeletal form characteristic of this group of rocks; garnet occurs associated with biotite and magnetite.

A further stage along this line of divergence is possibly provided by a rock which has felspar, quartz, and biotite as its main constituents. The turbid zoned felspar varies from oligoclase to andesine; the biotite is yellow to black and forms ragged plates; quartz is common. Prisms of dark bluish-green tourmaline are noteworthy. This mixed rock is very like the Kennethmont quartz-diorite¹ in its quartz, biotite, and felspar, but lacks the green hornblende of the true quartz-diorite. It is, of course, possible that the original igneous rocks of Saphook had as a member a rock already somewhat differentiated from the main gabbro type before contamination had occurred. Such a possibility, whilst by no means to be neglected, is rendered less likely by our experience of the very variable contaminated rocks of the Huntly Mass.

The second line of divergence from the normal hypersthene-gabbro is characterized by a very variable group containing cordierite. At Saphook it is impossible yet to trace that detailed destruction of hypersthene and the formation of biotite, cordierite, garnet, etc., so well seen in the Huntly Mass. The Saphook cordierite-bearing rocks are nearer the sedimentary than the igneous end of the series.

A member of this cordierite-bearing group is a rock made up in hand-specimen of black biotite plates and pinkish felspar in streaky, almost gneissose, association. In thin slice, the biotite builds large yellow to brown-black plates, usually ragged and often showing the skeletal or rudimentary forms characteristic of this suite. Cordierite is abundant in small grains, and shows magnificent pleochroic haloes and common sector-twinning. Amongst the felspars are found microcline, orthoclase, and andesine. Sillimanite forms fibrous needles in the cordierite and stouter blades in the biotite; greenish spinel and clots of magnetite complete the slice. An allied type is composed of quartz in patches and grains, abundant cordierite in large, slightly pinitized grains, pink garnet, yellow-red ragged biotite, and grains of andesine and magnetite. These abnormal rocks show

¹ H. H. Read, *Summary of Progress for 1919, 1920*, p. 25.

the great modification that the gabbro magma can undergo by the incorporation of sedimentary material.

It may be useful to combine these observations into the following statement of mineral composition :—

Hypersthene-gabbro : Labradorite, hypersthene, augite, magnetite.

Contaminated gabbros : Labradorite, hypersthene, augite, magnetite, together with biotite, quartz, orthoclase, microcline, andesine, garnet, tourmaline, cordierite, sillimanite, spinel.

RESULTS FROM THE HUNTLY MASS.

The Huntly Mass¹ of younger igneous rocks is about 16 miles from north to south, with an average breadth of 3 miles in an east and west direction. At many localities in this large area, contaminated gabbros are now known. Watt² originally described them from Wells Cuternach. I have found them extremely well developed at the following independent localities : (1) near Ward ; (2) Battle-hill Quarry ; (3) Castle Bridge, Huntly ; (4) Hill of Kinnoir ; (5) Rivestone ; (5) a great spread of about 1 square mile around Cuttle-hill ; (7) Fowlwood ; (8) Barry Hill ; (9) Wether Hill. The last three localities are in Banffshire. Most, but not all, of these localities are at the margin of the igneous mass. Here the contaminated gabbros form the matrix between lumps of partly digested hornfels ; the digestion may sometimes proceed so far that a fairly homogeneous contaminated gabbro results.

Watt gave an excellent description of the Wells Cuternach rocks, together with an analysis in which it was shown that over 50 per cent of the rock was composed of cordierite. He distinguished two stages of contamination : first, the formation of cordierite-norites, and finally the formation of garnet-labradorite-biotite rock.

The Cuternach locality presents several points of difficulty. The neighbouring igneous rock is a so-called picrite,³ which may be taken to form the basal part of the composite intrusion of the Huntly Mass. Between the picrite and the schists to the west, appear the Cuternach cordierite-norites. Three views may be taken of these relative positions.

(1) The basal picrite has been modified by the incorporation of sediment to produce cordierite-norite.

(2) Or there was an original norite intruded between the picrite and the sediments to the west to provide the igneous magma for the contaminated norite.

(3) Or the contamination of the original gabbro magma of the

¹ H. H. Read, *Summary of Progress for 1918, 1919*, pp. 28, 29.

² W. R. Watt, loc. cit.

³ W. R. Watt, loc. cit., p. 274. H. H. Read, *Summary of Progress for 1918, 1919*, p. 28.

whole Huntly Mass took place along its base before an ultrabasic bottom layer had time to collect.

It must be admitted that of these three possibilities the last is the most attractive, and would be readily adopted if one was sure that *any* kind of differentiation in place had occurred in the Huntly Mass.¹ On this point extremely conflicting evidence may be found if the whole of the mass is considered. As Watt remarked, it is unfortunate that these rocks of Cuternach occur in cultivated ground. No advantage can be obtained at present by dogmatic statements.

The remainder of the occurrences of contaminated norites are fortunately free from doubt. The original purely igneous rock is the great norite² of the Huntly Mass. This fine-grained bluish rock consists of ophitic, granular, or granitic associations of bytownite (Watt), hypersthene, augite, olivine, hornblende, biotite, magnetite, apatite, and zircon.

A summary of the study of the contaminated norites may be given. These rocks are extremely variable in texture and composition, and contain partly digested hornfels chunks. The minerals observed in the contaminated norites are :—

Cordierite, garnet, hypersthene, labradorite, andesine, orthoclase, biotite, spinel, sillimanite, magnetite, quartz, rutile, zircon.

This assemblage is like that already given for the Saphook contaminated gabbros. In the field, in hand specimen, and in slice, the contaminated gabbros of both the Huntly and Inch Masses are thoroughly alike.

FOREIGN OCCURRENCES OF CONTAMINATED GABBROS.

Professor Lacroix³ described the occurrence in the quarry of Les Prinaux at Le Pallet, Loire Inférieure, of xenoliths of mica-schist surrounded by a layer of cordierite-norite separating them from normal olivine-gabbro. Lacroix deduced that *both norite and cordierite-norite* had resulted from the incorporation of sedimentary material of suitable composition in the olivine-gabbro magma. At present I am not prepared to admit a similar origin for the norites of North-East Scotland. I am, however, in entire agreement with Lacroix as to the origin of the cordierite-norites, and have extended the group of contaminated gabbros to include many diverse kinds of assimilation rocks.

A. N. Winchell⁴ described the occurrence of cordierite-biotite-norites ("muscovadytes") along the contact of gabbro and schist in Minnesota; such contaminated gabbros are confined to the contact zone. Winchell considered the cordierite-norites to result from the absorption of aluminous material from the surrounding

¹ See H. H. Read, *GEOL. MAG.*, Vol. LXX, 1919, p. 370.

² W. R. Watt, loc. cit., p. 272. H. H. Read, *Summary of Progress for 1918*, 1919, p. 28.

³ A. Lacroix, loc. cit.

⁴ A. N. Winchell, loc. cit.

sediments. He also discussed the formation of quartz-gabbro and orthoclase-gabbro and concluded (*loc. cit.* p. 365) that the following modifications of the gabbro magma by sedimentary contamination had taken place :—

- (1) Digestion of aluminous sediment : cordierite-norite.
- (2) Digestion of siliceous schists or quartzite : quartz-gabbro.
- (3) Digestion of potassic rock : orthoclase-gabbro.

From the field relations and mineral composition it is apparent that the contaminated gabbros of Huntly and Saphook are of similar origin to those of Le Pallet and Minnesota. The following tabular statement exemplifies the close resemblance between the four occurrences :—

<i>Saphook.</i>	<i>Huntly.</i>	<i>Le Pallet.</i>	<i>Minnesota.</i>
{ Labradorite.	Labradorite.	—	Labradorite.
{ Andesine.	Andesine.	Acid andesine.	Andesine (rare).
{ Orthoclase.	Orthoclase.	—	—
{ Microcline.	—	—	—
{ Hypersthene.	Hypersthene.	Hypersthene.	Bronzite-enstatite
{ Biotite.	Biotite.	Biotite.	—
{ Cordierite	Cordierite	Cordierite	Cordierite
{ with haloes.	with haloes.	with haloes.	without haloes.
Garnet.	Garnet.	Almandine.	No garnet.
Quartz.	Quartz.	Quartz.	Quartz.
—	—	Staurolite?	Staurolite.
—	—	Graphite.	Graphite.
Spinel rare.	Spinel common.	Spinel common.	Spinel rare.
Sillimanite.	Sillimanite.	Sillimanite.	No sillimanite.

CONCLUSIONS.

In North-East Scotland there is a great development of gabbros contaminated with sedimentary material. By the incorporation of this sedimentary material in the gabbro magma rocks are produced in general of abnormal composition and characterized by minerals not proper to gabbro and often not proper to any purely igneous rocks. Sometimes, however, there may be produced a rock of undoubted assimilation origin, but which in mineral content approaches a purely igneous rock, though not a gabbro. The further exploration of the contaminated igneous rocks of North-east Scotland may, therefore, perhaps throw some light upon current theories of differentiation.

REVIEWS.

LE PLATINE ET LES GÎTES PLATINIFÈRES DE L'OURAL ET DU MONDE.

By LOUIS DUPARC and MARGUERITE N. TIKONOWITCH. Quarto, pp. vi + 542, with xi plates and atlas. Geneva: 1920.

PROFESSOR DUPARC'S researches in the Urals began in 1900 with an examination of the platinum deposits of the Koswinsky district, and have been extended until they include the central mountain-belt from $53\frac{1}{2}$ degrees to $61\frac{1}{2}$ degrees latitude. Important memoirs on certain districts have already appeared, besides numerous smaller contributions, chiefly petrographical, by the Professor and his coadjutors in the laboratory at Geneva. The work now before us presents in final shape the results of the whole investigation; while its scope has been further extended to include more briefly the other platinum-producing countries of the world, besides a number of technical matters.

The Ural chain is folded towards the west, and forms part of the Hercynian orographic system, though there is evidence of earlier movements on the same lines. In the axis of the chain appear crystalline schists, which are invaded by a great profusion of igneous rocks, mainly basic and ultrabasic, and it is to these intrusive rocks that the geological interest chiefly attaches. Of first importance are the dunites, which form oval masses with their long axes parallel to the mountain-chain. Each of the several occurrences exhibits the same relations, being bordered by a zone of pyroxenites, and again by an outer zone of gabbros and allied types. The main body so constituted is further traversed by numerous dykes, presenting a wide range of variety. Four chapters are devoted to the detailed petrography of these rocks; the dunite and allied peridotites; the pyroxenites and koswites, a group of rocks composed of olivine, augite, hornblende, chrome-spinel, and interstitial magnetite; the gabbros and their allies, including the tilaites, in which pyroxene is strongly preponderant over felspar, and often imparts a pseudo-porphyrific character; and finally the dyke-rocks, which embrace a great variety of types. Since many of these rocks have already been described, they do not call for particular notice here; but we may mention in passing the "plagiaplites" with primary brecciation, which afford strong ground for the belief that the uralitization of pyroxenes may be a magmatic process.

It has long been established on circumstantial evidence that the platinum found as grains in river-gravels and sands is derived from ultrabasic plutonic rocks; but so sparsely is it distributed in its primary situation, that only by prolonged search has such occurrence been verified. Our authors are able to prove directly that platinum is a normal constituent in very small amount of the dunites and pyroxenites of the Urals. In the former it is found either as small

grains idiomorphic against the olivine, or, more usually, in segregations of chromite. When platinum is present in the pyroxenites, it occurs interstitially as the latest product of crystallization.

It is well known that platinum never presents itself in nature as a pure metal, but always in alloy with other members of the "platinum group" and with iron. In the material studied, from the Urals and elsewhere, the authors distinguish among the constituents of the various mixtures five groups: iridium, osmides of iridium, palladium, platinum, and iron. The native iridium is rare, but "osmides of iridium", often in rhombohedral crystals, form part of most of the crude platinum of the Urals. The term employed seems to imply the existence of definite compounds, and indeed two types are discriminated and named, but the chemical analyses show much variation. Palladium is extremely rare in the Urals, though often present in the South American platinums. The Russian native platinum, unlike the Brazilian, contains iron as its most important element after platinum, and two types are recognized: polyxene, with 6 to 10 per cent of iron, and ferroplatinum, with 12 to 20 per cent, the latter being magnetic and of dark colour. The chemistry of the platinum group of metals is not without difficulties for the analyst. A discussion is here given of the various laboratory methods, and a large number of analyses are brought together.

Since exploitation of platinum in its original home is manifestly out of the question, it is the more important to study the alluvial deposits from which it is actually procured. The authors find that the present distribution of the platinum is not always in accord with the existing drainage of the country. In the case of the Koswa river-system, that which is now found in the tributary streams has been derived from older deposits, laid down when the river flowed at a higher level and followed a different course. A full description is given of the methods practised in prospecting and working platiniferous deposits. Then follows a detailed description of the numerous occurrences in the Urals, with more summary notices of those of Ronda in Spain, El Choco in Colombia, Brazil, British Columbia, Borneo, and other countries. The last three chapters deal with the metallurgical processes for treating the crude platinum, the various industrial uses of the metal, and statistics of production. We learn that in a period of 92 years the deposits of the Urals have produced 231,664 kilos (316.4 tons), exclusive of the large quantity lost every year by theft. In 1911 Russia furnished more than 93 per cent of the world's supply, Colombia ranking second with 6 per cent. Further exploration of the northern Urals, and especially of little known Colombia, may possibly lead to an enlarged output in the future, but it is certain that platinum can never be other than a rare metal.

Embodying a large amount of original research and summarizing practically all that is known at the present date, this will doubtless

long remain the standard authority on a subject which possesses great geological interest and economic importance. Throughout it is clearly written and liberally illustrated. The Atlas contains a general map of the region and detailed geological maps of the four most important districts, together with a series of plates illustrative of technological processes.

A. HARKER.

THE CORAL REEF PROBLEM AND THE EVIDENCE OF THE FUNAFUTI BORINGS. By E. W. SKEATS. Amer. Journ. Sci., vol. xlv, 1918. pp. 81-90.

IN this paper the author, who is highly qualified for the task, reviews the evidence afforded by the study of the material from the Funafuti bores in the light of recent developments in the study of coral-reefs, with special reference to the work of Daly and Davis. Incidentally, he makes the interesting statement that the experts who examined this material were not allowed to express in their reports any opinions as to the mode of formation of the atoll, but he believes he is correct in saying that they were unanimous in the conclusion that their results supported Darwin's theory of subsidence, and, in fact, were fairly susceptible of no other known explanation.

Three points specially dealt with in this paper are the submarine profile of Funafuti, Daly's and von Lendenfeld's views and diagrams of the development of atolls, and the mechanism of the filling of "lagoon moats". It is shown that all the core-material consists of shallow water organisms, mostly in the position of growth. No trace of deep-water organisms was found in any part of the core down to 1,114 feet, and no stratification was detected such as is inevitable in a talus deposit.

The filling of the so-called "lagoon moat" is shown to be due mainly to growth of *Halimeda* and other organisms, sediment playing but a subsidiary part, and it is noted that measurements have shown that some lagoons are becoming shallower, which effectively disposes of Murray's solution theory.

The general conclusion reached from this revision of the evidence is that the only cause capable of accounting for all the facts is subsidence. This is in exact accord with the opinion expressed by Professor Sollas in 1905, in a couple of notable essays on the results of the Funafuti expeditions.

CORRESPONDENCE.

A NATURAL "EOLITH" FACTORY BENEATH THE THANET SAND.

SIR,—A paper by Mr. H. Warren has been published recently by the Geological Society (*Q.J.G.S.*, vol. lxxv, part 3, No. 303, January, 1921), entitled "A Natural 'Eolith' Factory beneath the Thanet Sand", which, in view of the erroneous statements it contains, I ask permission to criticize in the pages of the *GEOLOGICAL MAGAZINE*.¹ Mr. Warren describes a certain series of naturally fractured flints found in the Eocene Bullhead Bed at Grays in Essex, and proceeds to compare these specimens with others—regarded by most archæologists as humanly fashioned—found under totally different conditions in various parts of this country. To those who take an interest in pre-historic archæology, the occurrence and nature of these pressure-fractured Eocene flints, such as Mr. Warren discusses, have been known for years past. In 1910 M. l'Abbé H. Breuil published in *l'Anthropologie* (t. xxi, 1910, pp. 385-408) a detailed account of a large series of specimens—similar to those found at Grays—discovered by him at Belle Assise in France, while in 1914 I was able to describe the flaked and broken flints which I had found in the Bullhead Bed at Coe's Pit, Bramford, near Ipswich (*Proc. Prehis. Soc. of E. Anglia*, vol. i, part 4, pp. 397-404).

It is not my intention to reopen the discussion upon the characteristics of these typical examples of flints broken by natural pressure, nor again to point out the fundamental differences between them and those found by Mr. Harrison upon the plateau of Kent, and of others of different forms recorded from the sub-Crag detritus bed. I would merely ask those who may regard Mr. Warren's paper seriously to compare the drawings of the specimens found by him with those of the Kentian and sub-Crag implements which have been illustrated in the publications of various learned societies. Such a comparison will at once show the marked differences between these shattered and fragmentary Eocene specimens, and the two other classes of flaked flints mentioned. I may say that I saw the selected material exhibited by Mr. Warren when he read his paper before the Geological Society, and I do not hesitate to affirm, with a full knowledge of all the facts, that it is preposterous to claim that the Grays specimens have any real bearing upon the flints found by Mr. Harrison and by myself. And I am amazed at Mr. Warren's lack of caution in describing, in his paper, such fractured specimens as he has found as "Kentish and sub-Crag forms of chipping" and "Carinate sub-Crag forms of chipping". The publication of such statements makes it perfectly clear that he has no real knowledge of

¹ Those who wish to refer to my published opinions upon this question will find them set forth in *Science Progress*, No. 41, July, 1916, pp. 37-50.

the Kentian and sub-Crag implements. If a comparison is made of the drawings which illustrate the Abbé Breuil's paper, already mentioned, with those published by Mr. Warren, it will be seen that the two series portray specimens of a very similar character. Both papers describe and illustrate fractured flints of the haphazard kind, such as would be expected to be produced by some natural, non-human force, and it would be easily possible, by imitating Mr. Warren's methods, to claim that at Belle Assise and at Grays there exist "Natural 'Palæolith' Factories", and so to emulate the efforts of those who, in the past, refused to believe in the human origin of any pre-Neolithic flaked flint.

I notice that on p. 243 (paragraph 4) of his paper, Mr. Warren draws attention to one of the Eocene flints, in the following words: "A polished mark, associated with a series of V-shaped incipient fractures, indicates the passage of an intermittent jolting force. . . . Among these Bullhead flints such marks are usually lines of high polish, and not scratches. Upon exposure to atmospheric influences the crushed flint would weather out and leave a slight groove."

I have never yet seen a "V-shaped" incipient fracture such as is described above, nor do I believe that it exists, except in Mr. Warren's imagination. These incipient cones of percussion—for that is what they are—are caused by the point of the agent of striation passing over the surface of the flint subjected to the striating movement. They are more or less circular in form, but, in such a case as Mr. Warren describes, none are complete, and a series of half-circles (occurring in a line) very close to, and sometimes overlapping, each other is to be observed. This line indicates the path taken by the agent of striation, and the succession of contiguous semicircles is caused by the numerous blows administered by the unevenly travelling point of the agent of striation.¹

In course of time small cracks appear to develop from the ends of and extend these incipient fractures (giving rise to what are sometimes known as "centipede markings", from their superficial resemblance in outline to the legs of this creature), and these extensions have, apparently, misled Mr. Warren, and have induced him to describe the incipient fractures upon his specimen as being definitely shaped like a V.

I am interested to see that he adopts the view, already published, as to the weathering out, under atmospheric influences, of such incipient fractures, but I notice that he omits to mention the original paper in which this matter was first made public. In case the suppositions contained in this paper should turn out, eventually, to be

¹ For a very complete and interesting description of analogous incipient fractures produced in the surface of glass by grinding and polishing the reader is referred to a paper entitled "More Notes on Glass-grinding and Polishing" by Mr. James Weir French (*Transactions of the Optical Society*, vol. xviii, January, 1917). In this paper Mr. French points out (p. 22) that the direction of the movement of the agent of striation was always found to be towards the *convex* side of the semicircular fractures.

incorrect, and Mr. Warren caused to bear a responsibility which there is no need for him to shoulder, I beg to state that the paper to which I refer will be found in *Science Progress*, No. 44, April, 1917, pp. 597–603. It is entitled “Scratches on Flints”, and was written by me.

On p. 247 (paragraph 6) of Mr. Warren’s paper a description is given of a large flake, the bulb of which is “cross-cut by the éraillure which was formerly supposed to be the exclusive character of the human blow”. Who is the unfortunate person who has been responsible for making such a palpably absurd statement as this? Perhaps Mr. Warren can supply me with the needed information, but whoever made such a statement must be singularly devoid of even a rudimentary knowledge of flint fracture. Mr. Warren’s paper is, in my judgment, not calculated to help towards the solution of the serious archæological problems it purports to discuss.

J. REID MOIR.

February 26, 1921.

THE GLACIATION OF IRELAND.

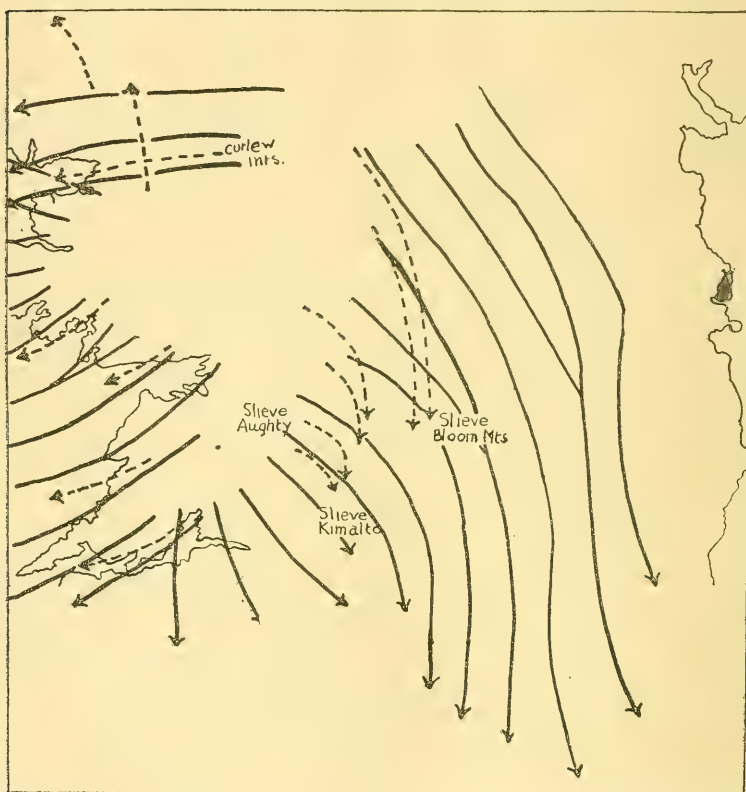
SIR,—I accept Professor Gregory’s implied reproof of my habit of “regarding views that” I “do not accept as simple mistakes”, and plead in mitigation of any penalty that my article in the February GEOLOGICAL MAGAZINE is only the second time in twenty years that I have indulged in public controversy. I should be greatly interested if Professor Gregory would suggest any logical method by which I could indicate my dissent from opinions with which I disagree without regarding their author as mistaken.

As to the general subject of the glaciation of Ireland, I am perfectly content to leave such of your readers as are interested to compare my criticism with what Professor Gregory deems an adequate answer.

There is, however, one point which raises wider issues than those of Irish Geology. In answer to my observation that the Roscrea esker is not at the northern end of the mountains, but a few miles south-west of the southern end, he retorts that “They” (the Roscrea, Clonaslee, Mount Mellick, and Maryboro’ eskers) “are part of one crescentic series around the northern end of the range. Moreover, the term Slieve Bloom Mountains is sometimes used (e.g. Phillips [*sic*] *Atlas of Comparative Geography*, and the map used in Carvell [meaning Carvill] Lewis’ *Glac. Geol. Gt. B. and I.*, 1894, opp. p. 83) to include the geological continuation of the range south-west of the Roscrea Gap”.

To make good this extended use of the name Professor Gregory does not appeal to his own map or to any authoritative map of Ireland, neither to Griffith’s nor the beautiful layered maps of the Ordnance Survey, but to Carvill Lewis’s little “track-chart” on the scale of 31·5 miles to 1 inch, in which—apparently to meet the exigencies of space—the lettering of “Slieve” begins about 5 miles south-west of Roscrea, and, actually, to a half-crown school atlas!

I now come to what strikes me as a matter of great gravity. In my previous communication I uttered a protest against a small portion of a map in W. B. Wright's *Quaternary Ice Age*, being enlarged up to the full breadth of a quarto page, and pointed out that the enlargement had been so badly done by the artist (a charitable assumption) that though the arrows indicating the ice-flow are stated to be "added from the map by Mr. Wright", some had been "swung round through angles of 20-40 degrees". Judge



of my surprise to learn that the whole work was deliberately done by Professor Gregory himself. He says: "Eleven out of the thirteen lines follow the originals precisely; the two easternmost are rather generalized to show the movement east of Lough Ree, and trend rather farther to the west than the nearest corresponding of Mr. Wright's lines."

May I be permitted again to use the obnoxious word "mistake"? Professor Gregory is mistaken, wholly mistaken, in supposing that only two of the lines were "rather generalized". Every

one of the lines in the Shannon Basin, making six in all, have been deflected, five of them considerably and one through an angle of 45 degrees, so as profoundly to modify the interpretation. The two "rather generalized" have been generalized to such effect that the arrow which should pass down the *east* side of the Slieve Bloom Mountains is carried down the *west*. The figure on p. 190 shows Wright's arrows by the full lines and Professor Gregory's version by broken lines. The superposition was done by photographic projections from a lantern slide in use here.

These may seem small matters, but it would strike at the very root of our confidence in scientific statement of fact if an author were permitted without protest to take any liberties he might choose with the work of another author and describe the result as "after W. B. Wright" or "added from the map of Mr. Wright".

PERCY F. KENDALL.

Leeds.

THE NOMENCLATURE OF PETROLOGY.

SIR,—Dr. Arthur Holmes, in his useful little book with the above title, disapproves of the term *syenoid*, which I have used as a contraction of felspathoid-syenite, giving as his reason that the suffix *-oid* has been used in other senses, as in granitoid, trachytoid, pegmatoid (Evans), and dacitoid (Lacroix). The matter is a very trivial one, but in the present involved condition of petrographic nomenclature no proposal for simplification should be dismissed without fair consideration, and the very examples that Dr. Holmes quotes show that he has not considered the matter fully. Of the four terms that he quotes, the last two are of later introduction than mine, so that I might at least claim the right of priority. This is true, too, of Lacroix's revival of "basanitoid"; and I cannot recall any other instance of a rock name in current use that ends in *-oid*. Then granitoid and trachytoid are adjectives, and should correctly be written granitoidal and trachytoidal, just like conchoidal and saccharoidal. But a more important consideration is just that *every* familiar suffix is used in various senses, and the ubiquitous *-ite*, for example, serves for rocks, minerals, fossils, meteorites, alloys, chemicals, official drugs, patent medicines, and a great variety of commercial products. I think, then, that Dr. Holmes' objection is not a very well-reasoned one.

The reason why it seems desirable to have a single word in place of the double-barrelled "felspathoid-syenite" is pretty obvious. In the first place these rocks are quite as distinct from the syenites as are—let us say—the monzonites, and they have therefore an equal claim to a distinctive name. In the second place, nepheline-syenite is long enough already, and when further mineralogical qualifications have to be added the name becomes unwieldy. A dreadful example of this is Dr. H. A. Brouwer's "ægirienamphiboolbiotietnepheliensyenietporphyr".

If another name is called for, as, I think, it is, the form syenoid (derived from feldspathoid *syenite*, but it can also be interpreted literally as "syenite-like") has an advantage over an entirely new name, inasmuch as it preserves the connexion with syenite and so imposes no fresh burden on the memory. Also it is only one of a whole series of terms which are all constructed on the same principle; and finally it is brief and euphonious.

I grant that the matter is a trivial one, yet I am convinced that in the judicious use of prefixes and suffixes we shall find the best solution of the difficulties of nomenclature. If this is "perversity", then I am guilty and unrepentant.

S. J. SHAND.

UNIVERSITY OF STELLENBOSCH,
GEOLOGY DEPARTMENT.
February 9, 1921.

"THE RELATIVE AGE OF CONCRETIONS."

SIR,—There is one paragraph in the interesting and suggestive paper by Mr. W. A. Richardson (in the March GEOLOGICAL MAGAZINE) over which I feel constrained to join issue with the writer. In the course of arguments in favour of subsequent formation of the concretions surrounded by "conformable" lines of stratification, and against the hypothesis that consolidation pressure" produces such effects, he quite rightly assumes that the latter would require the occurrence of similar "conformity" around fossils and other contemporaneous objects offering special resistance. And then he states (p. 118) "But it certainly is not". My experience (and surely that of every worker in the Chalk) would compel me to emend that sentence by omission of its last word. It is hard to find a specimen of *Micraster* or *Echinocorys* in the nodular parts of the *planus*-zone that is not considerably damaged by "slickensiding", precisely similar to that affecting the nodules themselves. While fully prepared to believe that these particular nodules are truly "subsequent" (although the fossils cannot be so), I cannot accept this particular argument. It is always unsafe to be "certain" about a negative.

H. L. HAWKINS.

UNIVERSITY COLLEGE, READING.
March 9, 1921.

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MAY, 1921.

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THE GEOLOGICAL MAGAZINE

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EDITORIAL NOTES.

THE Committee on British Petrographic Nomenclature that has been sitting for some months has now issued its report, which has been printed in the *Mineralogical Magazine*, and a separate copy has also been issued to every one entitled to receive No. 305 of the *Quarterly Journal of the Geological Society*. We should like to take this opportunity of congratulating the committee, and especially the chairman, Professor Watts, and the secretary, Mr. W. Campbell Smith, on this prompt appearance of the results of their labours. An additional number of copies of the Report are still available for distribution, first to petrologists abroad and then to any interested persons who may apply for them to the Secretary. It is not proposed here to offer any detailed remarks on the subject-matter of the Report, except to say that in our opinion a very wise course has been followed in suggesting the discontinuance of a considerable number of obsolete, ambiguous, and unnecessary names. In this respect the Committee might even with advantage have gone further than it has. At all events, it is satisfactory to find that the Committee is not to be dissolved, as we believe that a good deal of useful work may yet be accomplished by it in the direction of the simplification of a science hitherto overburdened and rendered unattractive by a ponderous nomenclature. It is hoped that some further comments on this subject, editorial and otherwise, will appear in a later issue.

* * * * *

THE Secretary for Mines has appointed Dr. F. H. Hatch, M.Inst.C.E., M.Inst.M.M., to be Technical Adviser to the Mines Department on questions relating to the Metalliferous Mining Industry.

* * * * *

ORIGINAL ARTICLES.

On Cycles of Sedimentation in the Eocene Strata of the Anglo-Franco-Belgian Basin.

By L. DUDLEY STAMP, M.Sc., A.K.C., F.G.S., King's College, London.

(Concluded from p. 157.)

C. THE LONDON "BASIN".

Landenian.—The Landenian is represented by the Thanet Sands and Woolwich and Reading Beds. The former seem to correspond to the two lower zones of the French Landenian, whilst the marine Bottom Bed of the Woolwich Series corresponds to the zone of *Cyprina scutellaria*. The present writer has given reasons for believing the pebble-bed separating the two to be due to a movement of uplift in the Wealden area.¹ In the east of the London district the marine Bottom Bed passes up into clays and marls crowded with estuarine fossils (Woolwich Beds); to the west into unfossiliferous mottled clays and fluvatile sands (Reading Beds). The extensive transgression at the time of the zone of *Cyprina scutellaria* is noticeable in the London Basin as it is in the Paris and Hampshire Basins.

Ypresian.—The Ypresian commences with the Oldhaven or Blackheath Beds. A slight upward movement of the Weald caused the sea to spread rapidly over the Upper Landenian estuarine flats, and at the same time great masses of pebbles tended to move from the northern flank of the Weald into the same area. In this disturbed marine region the invading Ypresian species lived side by side for a short time with the existing estuarine species of the lagoons, and so gave rise to the mixed Blackheath fauna. Continued transgression and more tranquil conditions resulted in the formation of the Base-ment Bed of the London Clay. The clay itself is much thicker in the east than in the west, and passes up gradually into sandy beds (Claygate Beds), and then into the continental Bagshot Sands. The latter are thicker in the west, and, as Mr. Whitaker showed many years ago, overlap the marine Ypresian, and come to rest on the continental Landenian, or even on the Chalk.² The London Clay is only 15 feet thick at Great Bedwin in the extreme west, about 50 to 60 feet at Newbury, but increases rapidly to over 400 feet in the North of London and about 490 feet in the Isle of Sheppey. In the London district it thins off rapidly southwards against the Wealden Dome. This is another proof that the Weald was being uplifted during Eocene times.

¹ Stamp and Priest, "Geology of the Swancombe Eocene Outlier": *Proc. Geol. Assoc.*, vol. xxxi, 1920, p. 191.

² Whitaker, "On the Western End of the London Basin": *Quart. Journ. Geol. Soc.*, vol. xviii, 1862, p. 258.

Lutetian.—The beds above the Ypresian in the London Basin occur in a somewhat limited area—the Bagshot District of Surrey and Berkshire. The marine Lutetian is represented by glauconitic clayey sands, etc., in which *Nummulites levigatus* has been found. These are the Bracklesham Beds of the Survey and recent authors. The Lutetian thickens eastwards from about 30 feet near Ascot to about 100 feet on St. George's Hill, near Weybridge. The upper part indicates shallower-water conditions.

Ledian or Bartonian.—The "Upper Bagshot Sands" (now usually called Barton Sands) of the London Basin comprise a series of sands over 200 feet in thickness with a very persistent and well-defined pebble-bed at the base. Marine fossils poorly preserved are found locally, and the fauna is generally considered as indicating a Lower Barton age. If that is so the Ledian is absent from the London Basin. Although "*Nummulites elegans*" (? = *N. Prestwichii*) was recorded by Prestwich himself in 1847¹ he seems to have favoured the correlation of these "Upper Bagshot Sands" with the Upper Bracklesham or Ledian.² A careful search for *Nummulites* in the ironstones should settle this question.³

D. THE BELGIAN "BASIN".

In many ways the Eocene strata in Belgium and North France differ from those in other parts of the Basin. Above the Landenian the succession is almost, if not entirely, marine. This is due, doubtless, to the absence of rivers bringing sediment from the east. At the same time the Palæozoic floor in Belgium is found at no great depth, and parts of it projected to form islands or rocky submerged shoals in the Eocene sea. This is particularly noticeable in the case of the Diorite masses of Quenast, etc., round which one finds conglomeratic beds of Landenian or Ypresian age. It is well to bear this fact in mind in considering the distribution of the deposits known as "Paniselian".

The beds can be grouped in the same six cycles as in other parts of the Basin. The succession has naturally often been compared with that in the Paris region, and the correlation is now well established. For that reason the diagram (Fig. 4) has been drawn to show the connexion with the London Basin.

Montian.—As in the Paris Basin, the Montian deposits are of restricted occurrence, being found principally in the "Bassin de Mons". The "Bassin de Mons" is a synclinal region running from west to east. It is partly an original basin of deposition, and must have formed a gulf-like inlet from the west. The Eocene rocks now form a very pronounced syncline due to later folding. The marine Montian consists of the famous Calcaire grossier de Mons—a very fossiliferous soft limestone—which, unfortunately, is rarely visible.

¹ Prestwich, *Quart. Journ. Geol. Soc.*, vol. iii, 1847, p. 393.

² Prestwich (in discussion), *ibid.*, vol. xxxix, 1883, p. 354.

³ White records *N. variolarius*, *op. cit.*, 1917, p. 270 (*Handb. Reg. Geol.*).

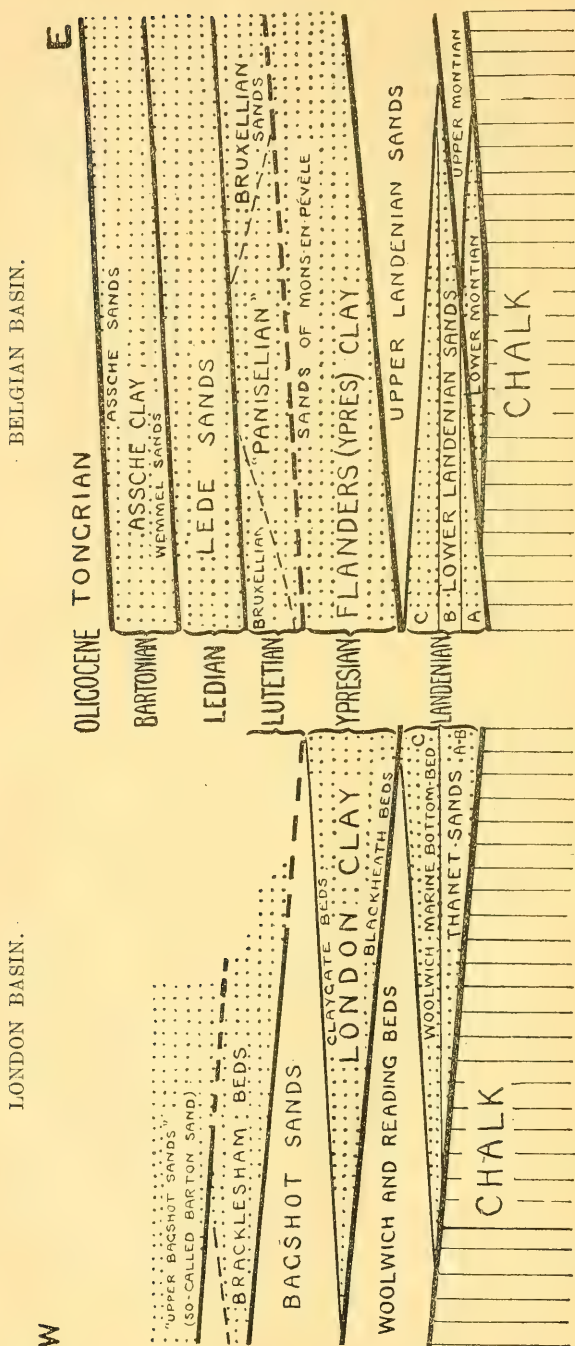


Fig. 4.—Cycles of sedimentation—London and Belgian Basins. Landenian Zones: A = zone of *Cyprina Morrisi*; B = zone of *Pholadomya Konincki*; C = zone of *Cyprina scutellaria*.

The Tuffeau de Ciply is a sparingly fossiliferous lateral phase of the same bed, and is exposed in several places to the south of Mons. The continental Montian thickens eastwards from Mons, and consists of dark lagoon clays, fluviatile sands, and lacustrine limestones, with *Chara* and *Physsa*.

Landenian.—The Landenian consists chiefly of glauconitic sands, with some harder beds—calcareous or siliceous—of “tuffeau”, especially at the base. It can be separated into the same zones as in France, and the three zones demonstrate a marked transgression.

During the time of deposition of the sediments of the zone of *Cyprina Morrisi* there seems to have existed in Eastern Belgium (Hesbaye) an isolated basin or tranquil gulf. In this area was laid down a basal sand (Sable d’Orp-le-Grand) followed by a considerable thickness of white chalky marl (Marne de Gelinden) with *Cyprina Morrisi* and numerous well-preserved plant remains. This is the “Heersian” of the older Belgian writers. The waters of the main Anglo-Franco-Belgian Basin invaded this area at a later date, and one finds the tuffeau with *Pholadomya Konincki* resting irregularly on the Marne de Gelinden.

The marine Landenian sands become less glauconitic in the upper part and frequently pass up into false-bedded and lignitiferous fluviatile sands. As one approaches the Ardennes one finds that these continental deposits occur as narrow bands filling river channels in the marine beds or even in the Chalk. As a rule the streams seem to have flowed from south-east to north-west, and point to a small quantity of sediment having been derived from this direction. As one would expect, the continental Landenian is of very local occurrence. Towards the north-west, as borings in the neighbourhood of Ostend have shown, estuarine clays of Woolwich type are present.

Ypresian.—As in the London Basin the Ypresian consists of a thick mass of clay (Argile des Flandres). There is a thin sandy basement bed and a line of pebbles at the base. The clay passes up into a very fine sand with *Nummulites planulatus—elegans* (Sables de Mons-en-Pévèle). Traced eastwards the clay grades laterally into more sandy littoral beds. The character of the latter demonstrates the tranquil conditions prevailing along the eastern shore of the basin. More to the north-west in the Flanders plain the main mass of the Ypresian clay passes up into sandy clays with beds of very fine sand, followed by more clay. Then follows a series of coarse glauconitic sands—the “Paniselian”. For the French geologists the “Paniselian” commences with the coarse sands (Paniselian of Cassel), but the Belgian geologists include the sandy clays and fine sands below in this stage. The coarse glauconitic sands which make up the bulk of the “Paniselian” occupy the higher parts of the hills from Cassel, in France, to the River Senne, north and south of Brussels. Over a considerable portion of this area there is a thin band of clay at the base. This is the *P 1 m* of the Belgian Geological Survey.

Lutetian.—There are good reasons for believing that the “Paniselian” is a local shallow-water representative of the lower part of the Lutetian. Its fossils on the whole seem to be intermediate between those of the Ypresian and the normal Lutetian. To the west, in the hills of Cassel and Mont des Recollets, it passes up gradually by loss of glauconite into the “Bruxellian” sands. The latter have the fauna of the lowest zone of the Lutetian—the zone of *Maretia Omaliusi*. As one goes westwards there is still a gradual passage from the “Paniselian” into the paler and more calcareous Bruxellian sands, but the latter become very thin, being only a foot or two in thickness at Mont Aigu, and are absent at Mont Kemmel.¹ It appears, then, that the “Paniselian” is a facies of the lower part of the Lutetian, deposited in a shallow sea stretching eastwards as far as Brussels. East of Brussels one has again the “Bruxellian”—siliceous or calcareous sands—of the age of the lowest zone of the Lutetian. Possibly the Lutetian sea transgressed from the north towards the Paris area, so that the “Bruxellian” deposits are slightly earlier in age than the zone of *Maretia Omaliusi* in the Paris Basin. In any case all the Bruxellian deposits are earlier than the zone of *Nummulites lævigatus*, except in the extreme west at Cassel, where the zonal fossil occurs in the higher part of the “Bruxellian” sands.

Further work on the “Paniselian” is very necessary, and the junction between the “Paniselian” and the Ypresian is still uncertain.

Ledian.—The Lutetian deposits must have been very considerably denuded before the deposition of the Ledian. Although the Lutetian zone of *Nummulites lævigatus* is nowhere found *in situ* in Belgium, this Nummulite occurs in enormous numbers, associated with other Lutetian fossils, in a rolled condition in the basal conglomerate of the Ledian. The Ledian consists of fine whitish sands, characterized by the presence of *Nummulites variolarius*.

Bartonian.—The Bartonian consists mainly of a grey glauconitic clay—the Argile d’Assche. Locally there are beds of sand at the base. These are the “Wemmelian” or Wemmel Sands, and they contain *Nummulites Orbigny* Gal.—*wemmeliensis* De la Harpe. Where they are absent the basal bed of the “Asschian” is formed by a sand extremely rich in glauconite and known as the “Bande noire”. The Assche Clay passes up into sands with *Nummulites wemmeliensis*.

They are succeeded by the Oligocene (Tongrian), of which the base does not always seem to be very clearly defined.

¹ Stamp, “Note sur la Géologie du Mont Aigu et du Mont Kemmel”: *Ann. Soc. géol. Nord*, vol. xliv, 1919, p. 115.

IV. NOMENCLATURE.

It may be useful to give here some reasons for the general names adopted for the cycles.¹

Landenian (Dumont, 1839, defined by Meugy, 1852).—The inapplicability of the terms Thanetian and Sparnacian have been mentioned above.²

Ypresian (Dumont, 1849).—The term Londonian of Mayer-Eymar (1858) is bad, since he confused the London Clay and Woolwich Beds. Also confusion with Landenian is inevitable. Dollfus prefers his own term Cuisian (1880), on the grounds that Cuise is a more fossiliferous locality, and that neither stratigraphy nor palæontology is to be observed at Ypres. On the contrary, Ypres is a typical locality in that the beds are of the familiar argillaceous type, common to the Hampshire, London, and Belgian regions (London Clay). At Marck, not very from far Ypres, Leriche has shown that the argillaceous sediments occur interbedded in certain localities with sands of Cuise type, and that the faunas of the London Clay and Cuise Sands occur in alternating layers. Moreover, fossiliferous horizons of London Clay species have recently been found in the Flanders plain round Ypres.

Lutetian (de Lapparent, 1883) is generally accepted.

Ledian (Mourlon & Vincent, 1887) was originally applied in Belgium to the beds with *Nummulites variolarius*. Auversian (Dollfus, 1880) was originally far more restricted in meaning.

Bartonian (Mayer-Eymar, 1858).—Although a much misused term, the Barton sequence is a very good one to take as a type.

V. CONCLUSION.

This paper is a brief resumé of the results of several years field work on the Tertiary deposits. For the sake of brevity, references have been confined to a few special points. The author regrets that it is impossible, for the same reason, to acknowledge individually his indebtedness to a large number of friends both on the Continent and in England. Without their cordial assistance the work would have been impossible.

Part of the expense of this investigation has been defrayed by a grant from the Dixon Fund of the University of London, and by the Layton Research Studentship of King's College (University of London).

Postscript.—(1) Belgian geologists have recently come to the conclusion that the Tuffeau de Ciply is not a lateral phase of the Calcaire de Mons, but is earlier (Danian) in age.

¹ Compare also Leriche, "Observations sur la Classification des Assises paléocènes et éocènes du Bassin de Paris": *Ann. Soc. géol. Nord*, vol. xxxiv, 1905, p. 383. Dollfus, "On the Classification of the Beds of the Paris Basin": *Proc. Geol. Assoc.*, vol. xxi, 1909, p. 101. Lemoine, *Géologie du Bassin de Paris*, 1911, p. 198 et seq.

² See also Leriche, "Sur la signification des termes Landenien et Thanetien": *Ann. Soc. géol. Nord*, vol. xxxiv, 1905, p. 201.

(2) The Paniselian is sometimes regarded as having been formed in *deeper* water than the Bruxellian.

(3) Recent study of the fauna seems to show that the fossiliferous horizon in the Flanders Clay at Bailleu, Ploegsteert (near Messines), etc., marks the base of the Lutetian (Paniselian facies), and that the Belgian geologists have been correct in regarding the series of sandy clays in the higher part of the "Argile des Flandres" as Paniselian.

The Boulders of the Travellers' Rest Gravel Pit, Cambridge.

By J. E. A. WHEELER, Christ's College, Cambridge.

ABOUT twelve years ago Dr. R. H. Rastall and Mr. J. Romanes published an account of the Boulders of the Cambridge Drift.¹ In this paper a list was given of the rock-types recognized at that time in the gravels of the Travellers' Rest Pit, situated about a mile north-west of the town of Cambridge on the Huntingdon Road. Since that time Professor Marr has paid much attention to this pit, among others, with special reference to the Palæolithic implements there found. He has embodied his results in two important papers.² In the course of this work Professor Marr collected a number of interesting erratics, and the same pit has also been investigated by many geologists connected with the University, both members of the Sedgwick Club and others. During the last ten years, though the North Pit has been abandoned, the South Pit has been very actively worked for gravel, and has been greatly increased in size. In consequence of this a large amount of additional material has been collected, including many new types, while some of the older specimens, whose origin had been left indeterminate by Rastall and Romanes, have been now identified. Hence it is felt that the time has now arrived when these more recent results should be put on record.

The Travellers' Rest Pit is excavated in the "Gravels of the Ancient River System" of the earlier literature. It is not proposed here to discuss its stratigraphical relations. On this point reference may be made to Professor Marr's recent publications, especially to the *Q.J.G.S.* paper, in which a sketch is given of the "face" of the pit. It is intended in this paper only to deal with the erratics found in the gravels.

The list given by Rastall and Romanes in their paper is as follows:—

Carboniferous Limestone, several, some striated.	
Millstone Grit, several.	
Basalts	} large and unusually well rounded.
Dolerites	

¹ *Quart. Journ. Geol. Soc.*, vol. lxxv, 1909, p. 246, et seq.

² *Quart. Journ. Geol. Soc.*, vol. lxxv, 1919, p. 204, et seq.; and *Proc. Camb. Phil. Soc.*, vol. xix, 1917, p. 64.

- Rhomb-porphry (2).
- (?) Nordmarkite.
 - Pink granulitic granite, two large specimens.
 - Orthophyre of North Berwick type.
- (?) Analcime-dolerite (Teschelite) of Forth Valley type.
 - Cheviot porphyrite and lava.
 - Coarse white granite.
 - Large concretion with *Serpula tetragona*.
 - A species of *Gryphæa*, intermediate between *arcuata* and *dilatata*.

To proceed to a detailed description of the new types recorded. The specimens may be classified according to their reputed source of origin, which sources may be conveniently divided as follows:—

1. Scandinavia.
2. Scotland and Scottish borders.
3. Lake District.
4. North-Eastern and Eastern England.
5. Source unknown.

Of necessity the majority of specimens are allocated to the last class.

To deal with the divisions severally, commencing with the Scandinavian types. The only specimens which had been recorded at the time of publication of Rastall and Romanes' paper, were rhomb porphyry and a doubtful nordmarkite, or, rather, I should say, these were the only certain types. Since that time several more specimens of rhomb porphyry have been collected, notably by Professor Marr, one of which is remarkably large, measuring 12 by 11 by 7 inches. This rock, however, is far from common at the Travellers' Rest Pit, though it is found in greater abundance elsewhere in the Cambridge district. Laurvikite, which has been recorded from the district before, has been collected at the pit, once only I believe, and that specimen a small and badly weathered one. One small specimen of the pink soda granite of Christiania has been collected.

Perhaps the most important discovery from the pit, however, is a small boulder with a violet-brown groundmass, in which are scattered grains of quartz, small orthoclase feldspars, and greenish plagioclase. This corresponds therefore very closely with the Särna porphyry, according to Milthers¹ description of that rock. A second specimen has recently been collected bearing a strong resemblance to the last, but with a smaller amount of quartz and without plagioclase, so far as can be seen by the naked eye. The groundmass also is dark grey, rather than violet-brown. This strongly resembles the specimens of the Elfdal porphyry in the Natural History Museum. These rocks therefore belong to the Dala group of porphyries, as described by Milthers, a type not hitherto recognized in this neighbourhood. On looking through the collection

¹ Milthers, *Indicator Boulders*, D.G.U. II, R. Nr: 23, Copenhagen, 1909; and *Geschiebe aus der Umgegend von Königsberg in Ostpreussen*, Phys.ök. Gesell. zu Königsberg, 1888.

made by Rastall and Romanes, no less than six boulders were found bearing a strong resemblance to them. They were collected from the following localities:—

(a) Two from fields north of the Madingley Road, 5 miles from Cambridge.

(b) Gravel pit, Milton Road.

(c) Deep Spring, Biddenham, Bedfordshire.

(d) Two found east of the "Golden Lion", Kingston.

Särna is in the Dala district a few miles from Elfdal itself, and about 200 miles north-west of Stockholm. The presence of Dala boulders in England has (according to Milthers) been reported rather indefinitely before.¹

The important Swedish indicator boulder—the Scanian basalt—has not been definitely found at the pit, but basalts are extremely common, and, owing to the multiplicity of Scottish types and the similarity of basalts generally, no definite results have been obtained.

Three interesting nordmarkites were collected last year. One on a heavy mineral separation yielded a quantity of copper; the other two were sliced, one having a special peculiarity in that riebeckite is developed instead of arfvedsonite, and the other shows strong affinities to this rock.

Three extremely interesting boulders were collected last year, all probably Scandinavian, but their exact locality is uncertain. The first type has been found twice and is a porphyry with extremely fine felspar phenocrysts up to 10 mm. in length, and showing intact crystal faces; the greyish-white groundmass contains abundant green specks which on microscopic examination proved to be ægirine. The second specimen is a gabbro with some affinity to the essexites: it contains some orthoclase, and the uralitic hornblende is blue in places, showing derivation from a soda-bearing augite. The other rock was collected as a largish boulder, and is a syenite with lepidomelane, and was found, when a slice was examined, to contain barkevikite. Neither this rock or the ægirine-porphyry could be matched in the collection of Scandinavian rock-types at South Kensington Museum.

The complete list of Scandinavian types which have been recognized at the pit may be summarized thus:—

Swedish.—Särna porphyry and related types.

Norway: 1. Rhomb-porphyry.

2. Laurvikite.

3. Christiania soda granite.

4. "Copper-bearing" nordmarkite.

5. Riebeckite-nordmarkite.

6. Nordmarkite showing affinities to No. 5.

Doubtful: Barkevikite-syenite.

Ægirine-porphyry.

¹ *Indicator Boulders* and V. Madsen, *Quart. Journ. Geol. Soc.*, vol. xlix, 1893, p. 114.

It is of interest to note that a boulder collected some time ago at Whitby by Dr. Rastall bears a marked resemblance to the Bredvad (Dala) porphyry, described by Milthers.

Turning now to the Scottish types many interesting specimens have been collected.

Firstly, we have the quartz-porphyry from Buchan Ness. This rock has fine phenocrysts of orthoclase, and plentiful quartz grains embedded in a dark, fine-textured groundmass. It is recorded by Rastall and Romanes as being found at Barrington, an exposure now unfortunately largely overgrown. The Barrington specimen was identified as the Buchan Ness rock by Dr. Bonney and Dr. R. Campbell. This year three specimens have been recorded from the Travellers' Rest Pit, but I am not aware of any having been found here previously. Two of the specimens were moderately large and in good preservation.

The next rock of interest is a beautiful alkali-granite with fine crystals of pink felspar and occasional patches of dark ferromagnesian mineral. I submitted this specimen to Dr. Bonney, who remarked on its strong affinities to both the Ross of Mull and Peterhead granites, the resemblance to the latter being more pronounced; the possibility of its being a specimen of the former being out of the question, and the finding of the Buchan Ness rock just referred to, seem to indicate its being of Peterhead origin. One specimen only has been recorded.

The finding of the Buchan Ness and Peterhead rocks here gives excellent proof of the presence of North Aberdeenshire erratics in the Cambridge drift, and touching on the interesting question as to how they reached this district, new facts have lately come to light. On the map on p. 49 of Mr. W. B. Wright's *Quaternary Ice Age*, the ice flow on the North Aberdeenshire coast is shown as roughly northerly. From this the inference might be that these types were transported indirectly, had it not been for a recent important discovery. In the report of a recent meeting of the Edinburgh Geological Society¹ there is an account by Dr. Bremner of the finding of a boulder of rhomb-porphyry at the Bay of Nigg, just south of the town of Aberdeen, and about 30 miles south of Buchan Ness. This discovery is of the utmost importance, showing as it does that the Scandinavian ice *did* reach the *mainland* of Scotland, and would therefore be sufficiently strong to deflect the easterly flows of the Highland ice in this district, in part at any rate, in a southerly direction, and thus probably accounted for the transport of the Buchan Ness and Peterhead rocks to Cambridgeshire.

The quartz-porphyry recorded from so many localities, not, however, including the Travellers' Rest, by Rastall and Romanes, and referred to by them as porphyry "x", has now been identified as being a Scottish type, where it is of fairly wide distribution, being

¹ GEOL. MAG., vol. lvii, 1920, p. 522.

a dyke rock of Old Red Sandstone age. It has lately been collected several times at the 'Travellers' Rest Pit, and can be easily recognized by the weathering out of the quartz grains on the "boulder surface" as black specks.

Cheviot rocks are common and call for no further notice, except that many types are found, including andesites, porphyrites, and porphyries.

Several boulders have been collected of the Old Red Sandstone, which must be erratics from either the outcrop at the Border or from that north of the Firth of Forth.

One of the basalts collected at the pit was sliced, and both the boulder and the slice were submitted to Mr. E. B. Bailey, of the Geological Survey of Scotland. He stated that this specimen was a basalt of the Dalmeny type, approaching in its richness in augite phenocrysts and poorness in felspar in the groundmass to the Hillhouse type, and would be matched exactly under par. *b*, p. 106, *E. Lothian Memoir* (1910).

With regard to the presence of Lake District rocks in this district, more and more evidence is being collected in favour. At the time of publication of Rastall and Romanes' paper the finds were as follows:—

Muscovite granite porphyry	} Kingston Lodge.
Andesite	
Andesite with old label: "Drift, Cambridge".	
Andesite with old label: "Observatory, Cambridge".	

All these andesites are remarkably similar to the andesites of the Borrowdale series. They are well-preserved, compact, dark-green rocks, in which are embedded small laths of felspar. Since then two more specimens have been collected, one in 1909, after the publication of the paper by Rastall and Romanes, at the Milton Road Pit, and one last year at the Travellers' Rest. Thus five similar specimens have been found, all bearing very strong resemblance to the Borrowdale lavas.

The muscovite granite porphyry confirms the other specimens, as it is identical with the Dufton Pike rock.

The cumulative evidence of these types really forces one to the conclusion that Lake District rocks have been transported to the Cambridge area.

With regard to class 4, the north-eastern and eastern English rocks, the following have been found:—

- Millstone Grit.
- Coal-measure sandstone.
- Carboniferous limestone.
- Jurassic "oyster bed".
- Several other sandstones (common).
- Porosphaera.
- ? Red Chalk.

The latter calls for special caution owing to its great similarity to the Silurian *Orthoceras* Limestone from South Sweden. Unless a specimen contains a fossil it is impossible to state definitely which rock it is.

Noticeable under this heading is the Palæolithic implement found by Professor Marr, which is made from a silicified oolite which Dr. Rastall has identified as being of Yorkshire origin. The rocks from unknown localities are as follows :—

(a) *Metamorphic* :

1. Garnet-mica-schist.
2. Hornblende-schist, with quartz veins.
3. Green mica-schist, turning brown in places.
4. Micaceous schistose conglomerate (quartz pebbles).
5. Gneissose granites (comparatively common).
6. Foliated granite with porphyritic microcline.
7. Very much altered gabbro.
8. Gneissose muscovite-biotite-granite.
9. Many quartzites of varying composition.

(b) *Igneous*.

1. Muscovite-granite-porphyry.
2. Microgranites, chiefly pink.
3. Many granulites.
4. Many granites.
5. Pegmatite.
6. Markfieldite.
7. Dolerites (common).
8. Felsite.
9. Basalts (common).
10. Three types of rhyolites.

The last is an important point, owing to their practically negligible development in the east of Scotland.

(c) *Sedimentary* :

1. Carboniferous chert.
2. Arkose (Sparagmite).

In conclusion I should like to express my gratitude to Dr. Bonney and Dr. Rastall for their great kindness in identifying many of the specimens.

Preliminary Note on the Rocks of Darfur.

By CAPTAIN HUBERT LYNES, C.B., C.M.G., R.N., and
W. CAMPBELL SMITH, M.A., F.G.S.

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IN the course of a journey from El Obeid to Jebel Marra, in Darfur, Captain Hubert Lynes collected a number of the rocks from the volcano of Dereiba and from various other points on the route, shown in the map (Fig. 1). The rocks of this area have not been described hitherto. The following notes give a brief description of the nature of the country, with petrological details of the rocks collected.

Darfur is a vast plain, clad with bush and scrub, about one-fifth as large as the combined area of the British Isles, with a mean altitude of some 2,300 feet above sea-level. The highest part of this plain lies in the centre of the Province, whence it slopes very gradually downwards in all directions, except, perhaps, to the north. The surface is undulating with huge mile-long sweeps of almost imperceptible gradient, broken only in a few places by shorter and steeper undulations, which form low rolling hills.

The only important structural features which rise from the plain of Darfur are the mountains of Jebel Marra, including the extinct volcano of Dereiba, some high ground observed by Tilho round Mount Durbulla, in approximately lat. 14° N., long. $23\frac{1}{4}^{\circ}$ E., and numerous groups of lower hills, mainly in the northern part of the Province, rising on the average to about 1,500 feet above the plain. Of the last the most isolated and singular group is that of Jebel Meidob, some 130 miles N.E. of El Fasher, which is reported to contain a crater and a salt-lake.

Between the eastern borders of Darfur and the White Nile stretches the Province of Kordofan, also in the main a vast bush and scrub-clad plain partly studded with denuded hills and kopjes, which to the south merge into the mountainous country of the Nuba Mountain Province. Some of the rocks of this area have already been described by Linck.¹ Before starting on his main expedition, Captain Lynes went south to Dilling, following a route some 12 miles to the west of the El Obeid-Kadero route taken by Linck. The first rocks noticed by Lynes on the El-Obeid-Dilling route were at Khor el Haggis. The specimen collected here (48)² is a typical *troctolite*, consisting of equigranular (2 mm. grain) olivine and basic labradorite, near $\text{Ab}_{37}\text{An}_{63}$. The felspar is quite fresh, and is traversed by radial cracks emanating from the olivine, which is partly serpentinized, though less so than in the *troctolite* of Coverack Cove (Cornwall).

¹ G. Linck, "Beiträge zur Geologie und Petrographie von Kordofan": *Neues Jahrbuch für Min.*, etc., B.B. xvii, 1903, pp. 391-463.

² The numbers in brackets are the serial numbers of the specimens as recorded in the rock-registers of the Department of Minerals, British Museum (Natural History).

The figure of the latter rock in Harker's *Petrology for Students*, 1919 (fig. 24, p. 80) affords a good representation of the Khor el Haggis rock.

The granite of Dilling has been described by Linck.¹ Specimens (45) collected by Lynes show the proportion of potash-felspar (microcline and micropertthite) to oligoclase to be 2:1. Linck describes numerous dark inclusions in the granite of Kadero, to the east, and they are evidently abundant in the granite of Dilling too. Those collected (46) are fine-grained (0.08 mm.), equigranular aggregates of biotite and felspar (? orthoclase), quartz, and ilmenite (or magnetite), with abundant round grains of sphene, and fine needles of apatite crowding the felspar hosts. These inclusions carry some large crystals of plagioclase full of inclusions. The plagioclase is albite-oligoclase. One crystal showed a more acid centre, with inclusions of blebby quartz.

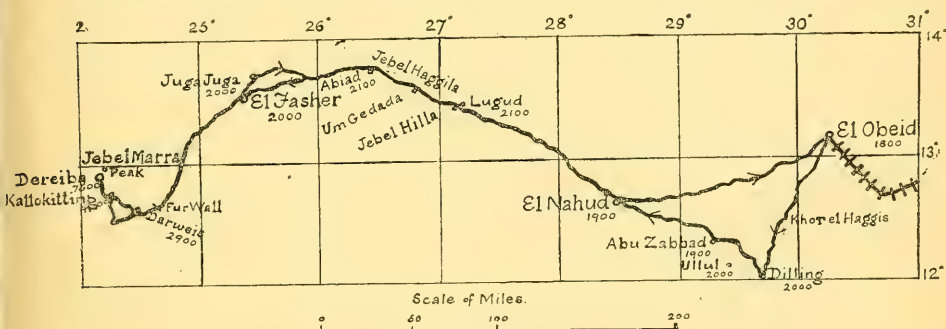


Figure 1.

Fragments of very weathered granite (44) found on a hill near Ullul seem the most westerly representative of the Nuba Mount granites, but at 30 feet, in a well-boring at Abu Zabbad, occurs a pure white pegmatite or *graphic granite* (43). It consists of orthoclase, albite-oligoclase, and quartz, the two last often graphically intergrown, in plates of about 1 cm. in average diameter, with occasional plates of biotite altering to chlorite. Zircon was the only accessory mineral observed.

On the direct route from El Obeid to El Fasher the ground is at first covered with the hard red sand, like that which is so widespread in Kordofan. To the south the Nuba Mountains are seen in the distance, but near the route a very occasional little kopje or rocky outcrop is all that is seen to break the level plain.

At Jebel Waled, 6 miles east of Nahud, sedimentary rocks appear. They are similar to those forming the Lugud Hills, which are described below. A well-boring at Nahud is in pale yellow friable sandstone, containing pebbles of chalcedony (40).

¹ Loc. cit., p. 407.

Soon after leaving Nahud tracks of blown sand are encountered. The hitherto imperceptible undulations contract, and trekking in the soft sand, with its frequent ups and downs, becomes tedious. The screen of bush on both sides of the track deprives the traveller of any view of the country to right or left, except on rare occasions, and then, when these glimpses of the distance are obtained, it is only on the horizon that any features stand out above the prairie-like landscape.

On crossing the frontier into Darfur, the same character is maintained, but with ever-increasing sand, until Jebel Hilla and the Lugud Hills appear, a welcome sight to the traveller, not only by reason of their fantastic forms and unusual colouring, but also as marking the beginning of the "game" country. These hills form a low range flanking the track on the north from Lugud to Abiad. Seen from the south they present a continuous series of flat-topped hills carved by denudation into a variety of shapes, fantastic pillars and "cathedral" masses rising from or flanking the table-tops in endless profusion, and rendered the more remarkable by their many colours, garish yellows, reds, pinks, and purples predominating among light greys and darkest browns. They are formed of sandstones and clays, apparently unfossiliferous, and, as far as can be judged from photographs, everywhere horizontal.

It is not practicable to publish here any of the photographs of these hills, but there is a striking similarity between the type of scenery north of Lugud and that portrayed in Col. Tilho's photographs of the peaks of Dourdouro in Erdi, 300 miles to the north-west, to which the reader is referred.¹ So striking is this similarity that one is tempted to hazard the suggestion that the sedimentary series of Erdi has its south-easterly prolongation in these hills between Abiad and Lugud, with an outlier or further extension to the east at Jebel Waled, near Nahud.

Specimens of these rocks from Jebel Haggila, between Abiad and Um Gedada, are yellow friable sandstone with a little muscovite, pale purple fine-grained sandstone, with occasional pebbles of white quartz, and quartz-conglomerates with hard black limonitic cement (32). At Lugud there are similar sandstones, pink and red, with thin bands rich in hematite (33). In addition there occur some fine decimillimetre-grained clayey sandstones, or sandy clays (33c), rather powdery to the touch, pale cream to palest violet in colour, with irregular streaks of pale lavender tint, which are more sandy and coarser in grain than the lighter coloured portions. On a low 50 ft. kopje, Jebel Hilla, 5 miles south of Lugud, these clayey sandstones occur near the top, and are here associated with pink, white, and pale-buff quartzites (35), very compact and fine-grained. The lower part of the hill consists of dark red friable false-bedded sandstone. These pale violet clayey sandstones seem to be an easily

¹ Jean Tilho, *Geogr. Journ.*, vol. lvi, 1920, p. 93.

recognizable lithological type, and it is their presence at Jebel Waled, where they are being quarried for building purposes, that makes it possible to trace there an extension to the east of this series of sediments.

West of Abiad, the "cathedral peak" country is succeeded by 30 or 40 miles of "goz" country, rolling sandy hills among stretches of level plain, in which the sands are sometimes pebbly and hard and clad more with scrub and grass than with bush.

Crossing the sandy "goz" belt, the track enters a new type of rocky hill country within 30 or 40 miles of El Fasher. The view looking south-west and north-west from a kopje 3 miles north of Juga-Juga shows a few low conical hills projecting here and there from a vast sandy plain, with hill-ranges in the far distance. Here the country seems to be formed of *metamorphic rocks*. Fragments of pink and green *epidotized aplite* (28) were noticed in the "khors" round Juga-Juga. Specimens from one of the low conical hills, "boulder kopjes," are of *biotite-gneiss* (30) and *biotite-amphibolite* (29). The latter is a fine-grained, equigranular, dark-green rock, and consists of brown biotite and green hornblende, with acid oligoclase, some orthoclase, and quartz. The accessory minerals are magnetite (or ilmenite) and apatite in small crystals. Nine miles south of El Fasher a vein of compact white quartz (27) forms the top of a small "kopje", 120 feet above the level of the plain.

Jebel Marra lies some 70 miles W.S.W. of El Fasher. It is a large mountain mass, extending perhaps 50 miles north and south and 20 east and west, with much of its area at a mean elevation of 8,000 feet above sea-level. It forms the dominant mountain-group between the Abyssinian Plateau and the mountains of Nigeria and the Cameroons, while in a north and south direction the nearest high features are the great Equatorial mountains on the one hand, and on the other the Tibesti Range, with the high ground round Mount Durbulla as a sort of connecting-link. The part of these mountains visited was the extreme southern end of the upper zone, where is an extinct volcano with a soda-lake, Lake Dereiba, on the crater-floor at 7,500 feet, and with peaks on the crater-wall rising to 10,000 feet above sea-level.

The route taken from El Fasher to Jebel Marra skirted the mountain system, passing up a more or less gradual ascent, through a heavy sandy belt, to a rocky country and the outlying hills of the Jebel Marra system itself. Here foothills of fantastic shapes fringe all the eastern base of the massif. The vegetation grows more succulent as one gets south, until at Kallokitting, 4,000 feet, at the beginning of the main ascent, there is perennial water in the Wadi Ghindi and quite rich vegetation wherever the water or moisture rises to the surface.

An outlying foothill between Darweis and Kallokitting consists of *biotite-granite rich in oligoclase*, of which two specimens were collected (25). A large slab of the same kind of granite was seen at

Kallokitting, 12 miles to the north (24). The only other specimen obtained from this area is a fragment of a quartz-vein with patches of muscovite, taken from the "fur wall" near Darweis, and believed to occur in situ in the vicinity (26).

One specimen of the granite contains a few flesh-coloured phenocrysts of micropertthite, 1-2 cm. in length, and set in an equigranular, millimetre-grained, dark groundmass of oligoclase, quartz, and biotite, with interstitial microcline. Magnetite, apatite, and orthite are accessories. The oligoclase is subhedral, and has strong zonary bands of inclusions. The micropertthite phenocrysts enclose oligoclase and numerous rounded patches of quartz. The proportion of potash-felspar (micropertthite) to oligoclase is about 6 : 5, as determined by the Rosival method. The other specimen is non-porphyritic, orthoclase not exceeding 0.6 mm. in diameter. It contains the same minerals as the porphyritic type present in similar proportions. But for the absence of sphene, the subhedral development of the oligoclase, and the somewhat greater abundance of biotite, this granite compares well with the Shap granite. It would be classed by Hatch with the "adamellites", and by Iddings with the "quartz-monzonites".

From Kallokitting begins the ascent to the crater of Dereiba. This extinct volcano was visited by Mr. J. A. Gillan and Captain H. F. C. Hobbs when on patrol duties in 1918, and the latter published an excellent general description of the crater and of the ascent to it, together with a rough map of the crater itself.¹

The crater is from 3 to 4 miles in diameter, surrounded by walls 2,000 feet above its floor, and contains two lakes. One, deep and not over-saturated with salt, occupies a subsidiary crater within the main one. The other is shallow and is surrounded by a rim of salt, consisting of carbonate and chloride of sodium (25a). Captain Lynes collected samples of water of both lakes, and analyses of these were made by the Wellcome Research Laboratories in Khartoum. The results of the analyses are given in the appendix.

The first exposures of volcanic material were met in the ravines in the foothills above Kallokitting at about 4,000 feet. The sides of the ravines are formed of loose volcanic tuffs (23), some red, others grey or pale brown. The pale-coloured tuff contains much felspar and brown glass. In the crater floor itself white pumice seems to be abundant, and the walls in places consist of light yellow tuff with small lapilli (20), and sometimes of a very fine-grained (0.04 mm.) ash or tuff (21), which readily falls to powder. The latter consists mainly of orthoclase or anorthoclase, with some glassy material and minute needles of pyroxene. A cream-coloured trachyte with

¹ H. F. C. Hobbs, "Notes on Jebel Marra, Darfur": *Geogr. Journ.*, vol. lii, 1918, pp. 357-63.

Capt. Hobbs' altitudes, for reasons which he himself explains, are inaccurate. Capt. Lynes, who considers his observations correct to within 200 feet, climbed a 9,500 ft. peak (6,000 feet in Hobbs' map, loc. cit., p. 362), and judged several peaks viewed thence to be up to 10,000 feet or over.

porphyritic orthoclase (up to 6 mm. in length) seems abundant at about 8,000 feet; the specimen of this rock (17) is too much weathered to be examined in thin section. A dark bottle-green obsidian (19) was found as rounded masses probably embedded in tuff. It contains a few phenocrysts of felspar with the optical properties of a soda-bearing orthoclase. The obsidian shows perlitic structure strongly developed and on a very fine scale, the glass splintering very readily into minute fragments.

The remaining specimens from Dereiba were, with three exceptions, collected from the top of a peak on the crater-wall (the 6,000 feet peak of Hobbs' map), the height of which Captain Lynes determined as 9,500 feet. Before proceeding to the description of the volcanic rocks reference must be made to the occurrence on the top of this peak of large blocks of rocks which present the characters of metamorphosed, foliated, igneous rocks. The specimens collected include a *biotite-bearing hornblende-gneiss* (7), a fine-grained white *gneiss poor in biotite* (11), and a *hornblende-schist* (9) with labradorite as the predominant felspar, and rich in ilmenite and sphene. There is no evidence at present of the exact mode of occurrence of these foliated rocks.

The volcanic rocks are represented by nine specimens, which are classified as follows:—

QUARTZ-BEARING SODA-TRACHYTE.

These (1 and 3) correspond very closely to the "phonolitic quartz-trachyte" described by Prior from the Great Rift Valley.¹ They are pale grey, often stained brown, with phenocrysts of anorthoclase, 1–2 mm. in length, in a fine-grained groundmass of lath-shaped orthoclase or anorthoclase, with interstitial micro-pæcilitic quartz and micro-ophitic patches of ægirite, cossyrite, cataphorite, and, more rarely, arfvedsonite. There are a few micro-phenocrysts of ægirite-augite, and rounded crystals of olivine with dark resorption borders are nearly always present.

The pleochroism shown by the *cataphorite* in these rocks is X = pale yellow; Y = smoky brown with rose-red tinge to dark brown, almost opaque; Z = smoky brown with green tinge to olive-green.

Two specimens (15) of a similar rock were collected from the entrance to the main crater at 8,000 feet. In these the felspar-laths are shorter, the quartz is not micro-pæcilitic, and the soda-amphiboles are mainly represented by cossyrite. Grey-green augite occurs as micro-phenocrysts in addition to ægirite-augite.

SODA-TRACHYTE.

One specimen (2), with phenocrysts of anorthoclase and rather darker in colour than the above, resembles closely the second type (No. 357 from Kamasia) of Prior's "phonolitic trachytes",² but

¹ G. T. Prior, *Min. Mag.*, vol. xiii, 1903, p. 342.

² Loc. cit., p. 241.

differs in containing rounded crystals of olivine and a few crystals of labradorite and pale-yellowish augite, which seem quite foreign to a rock of this nature. The labradorite is in one case enclosed in a crystal of anorthoclase; in another case the plagioclase is surrounded by a granular zone of untwinned felspar, augite, and magnetite. The phenocrysts of augite, wherever seen, are surrounded by a zone of small granular augites. Both the augite and the labradorite have the appearance of xenocrysts. This rock also contains numerous patches, 0.2 mm. in breadth, with rectilinear boundaries and made up of blebs of an opaque mineral doubtfully referred to cossyrite; these are probably pseudomorphs, but there is no evidence in the rock as to their origin.

QUARTZ-BEARING RIEBECKITE-TRACHYTE.

Two specimens (4 and 5) present a striking resemblance to the sölvbergites (Abuna Alif type) described by Prior¹ from the neighbourhood of Adowa and Axum, in Abyssinia, and which he compared to Brögger's sölvbergites from the Christiania district. The fresher specimen is cream-coloured, with minute black specks, giving the rock a blue-grey colour, stained red in patches. It resembles the Abuna Alif rock in texture, and in turbidity of the felspar laths, but differs in the possession of a few small phenocrysts (1.8 mm. $\times$ 0.8 mm.) of anorthoclase, in the presence of quartz as interstitial patches sometimes 0.1 mm. in diameter, and in the presence of abundant *riebeckite* in place of *ægirite*.

The mineral here referred to *riebeckite* shows two cleavages intersecting at about 120° , $X:c = 5^\circ$, and pleochroism:—

X = very deep blue-green.

Y = very dark blue, almost black.

Z = pale yellowish-green to olive-green.

Some sections suggest *ægirite*, but the green shades for X and Y are always very dark. A very similar rock (5) from the same locality is bright red in colour, which is due to the complete decomposition of the soda-iron-silicate, which may have been either *riebeckite* or *ægirite*.

There is no evidence as to whether these rocks occur as dykes or flows. On account of the trachytic texture they are classed for the present as trachytes, but their close similarity to Prior's sölvbergites from Abyssinia must be borne in mind.

ANDESINE-BEARING KENYTE.

This specimen (6) is not strictly comparable with any of the rocks hitherto described from East Africa, but its relation to the kenytes is evidently a close one, and it is still more closely related to those rocks of South Victoria Land which Prior has referred to as inter-

¹ G. T. Prior, *Min. Mag.*, vol. xii, 1900, p. 267.

mediate between olivine-basalts and kenytes,¹ and which Jensen described later as basic kenytes or plagioclase-kenytes.²

The hand-specimen shows small phenocrysts of felspar, averaging 0.6 mm. in length, in a dull glassy base. Under the microscope the groundmass is seen to be very dark, almost opaque, with scattered microlites of felspar giving straight extinction, possibly anorthoclase, but too thin to be determined with certainty. The other crystals in the glassy groundmass are olivine or its deep-red alteration product, one or two pale yellow crystals of augite, 1 mm. in diameter, several opaque black lozenge-shaped pseudomorphs possibly after hornblende, a few smaller augites of a pale-green colour, and one or two rounded flakes of dark-brown biotite. The felspar phenocrysts are of two kinds, basic andesine, near Ab₁ An₁, and anorthoclase, the latter being present in slightly smaller amount than the andesine. The anorthoclase forms tabular Carlsbad twins, of which the ends are rounded and the sides are frequently embayed by patches of groundmass. It occasionally encloses olivine or its alteration products. The andesine tends to develop euhedral outlines and contains inclusions of groundmass, and in one case small crystals of apatite. In addition to the phenocrysts of felspar the section shows five or six rounded crystals of olivine.

MUGEARITE.

A specimen chipped from a boulder in the Wadi Ghindi at about 7,500 feet (22) is a fine-grained blue-grey rock with trachytic texture mainly composed of lath-shaped crystals (0.2 mm. × 0.02 mm.) of oligoclase, associated with orthoclase, granular augite, and magnetite, with a few small phenocrysts (< 0.4 mm. diameter) of olivine and magnetite and occasional brown crystals of apatite. This compares so closely with the *mugearites*, described first by Harker³ and later by others, that one has no hesitation in assigning it to this species.

By the courtesy of Dr. H. H. Thomas I have been able to examine Dr. Harker's type rock from Druim na Criche, near Portree, Skye, and the other mugearites described from time to time by members of H.M. Geol. Survey.

Compared with Harker's type, the Wadi Ghindi rock is much poorer in olivine. Another point of difference is the presence of small phenocrysts of felspar, giving symmetrical extinctions of up to 11°, and consisting of oligoclase slightly more basic than that of the small laths, and sometimes showing a slightly more acid outer zone. The groundmass contains more augite and less magnetite than the type rock, and the augite is granular and not ophitic. The

¹ G. T. Prior, "National Antarctic Expedition, 1901-4": *Nat. Hist.*, vol. i, 1907, p. 106.

² H. I. Jensen, "British Antarctic Expedition, 1907-9": *Geology*, vol. ii, 1916, pp. 107-9.

³ A. Harker, "The Tertiary Igneous Rocks of Skye": *Mem. Geol. Surv. U.K.*, 1904, p. 264.

felspar laths are slightly larger. They give straight extinction and are oligoclase; orthoclase is present, but is less conspicuous than in the type. Apatite does not occur as abundant small crystals, but is represented by a few small prisms, coloured brown by lines of small inclusions and showing pleochroism: X = dark smoky brown, Z = yellowish-brown. Precisely similar apatites are found in mugearites from East Lothian and from Pembrokeshire.¹ The brown hornblende and biotite present in the mugearite of Skye and of other localities is absent. The Wadi Ghindi rock has a density of about 2.6, and is probably more acid than Harker's type.

With the exception of the mugearite and the andesine-bearing kenyte, the above rocks compare very closely with types described from the East African volcanoes. It is interesting to note the occurrence of rocks with similar affinities among those found by Lieut.-Col. Tilho at the volcano of Emi Koussi, in Tibesti, 600 miles north-west of Jebel Marra.² Professor Lacroix has not given detailed descriptions or figures of these rocks, but the cataphorite-bearing trachyte mentioned³ will doubtless be found to compare closely with the soda-trachytes or quartz-bearing soda-trachytes above described. The descriptions of the crater of Emi Koussi show that in form it closely resembles the crater of Dereiba.⁴

[Captain Lynes has now returned to Darfur, and intends making a long stay in Jebel Marra to study its natural history. It is hoped that after his return it will be possible to furnish further details of the geology and petrology of the district. In the meantime these preliminary notes may serve to indicate the nature of the rocks which occur in this part of Africa, and to show what interest may be attached to collections from remote parts of the world of fresh rocks taken in situ, carefully located and carefully labelled.—W. C. S.]

APPENDIX.

Report of the examination of a sample of water sent by Capt. Hubert Lynes, R.N., and received on June 7, 1920.

Sample No. 5728, labelled: "Water and a little green scum from 'Salt Lake', Jebel Marra Crater; altitude 5,700 feet."

The green scum referred to had disappeared, but there was a small amount of dark green sediment, showing organic structure, at the bottom of the bottle.

Sample No. 5729, labelled: "Water from 'Fresh Lake', Jebel Marra Crater; altitude 7,500 feet."

Analysis gave the following results, which are expressed as parts per 100,000 parts of water:—

¹ H. H. Thomas, "The Skomer Volcanic Series": *Quart. Journ. Geol. Soc.*, vol. lxvii, 1911, p. 197, fig. 9b.

² A. Lacroix, *C.R. Acad. Sci. Paris*, vol. clxix, 1919, pp. 401-7.

³ *Ibid.*, p. 404.

⁴ A. Lacroix, *C.R. Acad. Sci. Paris*, vol. clxviii, 1919, pp. 1237-40, and vol. clxix, p. 403.

	Sample No.	Sample No.
	5728	5729
Total solids	5,187	552
Containing :—		
Chlorides (as Sodium Chloride). .	1,587	174
Alkalinity (as Sodium Carbonate) .	3,364	304
Nitrates	trace	trace
Nitrites	absent	absent
Calcium	4	3
Magnesium	0·2	0·2
Suspended matter	small amount	nil

A very small quantity of sulphates was present in both samples.
No examination was made for ammonia.

(Signed) H. MARTIN,
Acting Government Chemist.

WELLCOME RESEARCH LABORATORIES,
GORDON MEMORIAL COLLEGE,
KHARTOUM.

July 11, 1920.

Tertiary Gravels of the Buchan District of Aberdeenshire.

By J. S. FLETT, F.R.S., and H. H. READ, F.G.S.

CAPPING many of the hill-tops of the Buchan district of Aberdeenshire there are extensive spreads of gravel containing pebbles of white quartzite and of flint. Their north-western limit is on the Delgaty estate, near Turriff, where, at an elevation of 350–400 feet, there is a small patch of quartzite gravel a mile and a half to the north-east of the town. Nearly eight miles to the south, on Windy-hills, two miles north-east of Fyvie, a more extensive outlier occurs. These two patches are shown in Fig. 1. The Windy-hills spread is nearly a square mile in area, and it occupies the summit of a low flat-topped ridge at an elevation of 370–400 feet. Like the Delgaty gravels, it is evidently the remains of a deposit formerly much more extensive and reduced greatly in area by denudation. It consists mainly of white quartzite pebbles, flint pebbles, and white clayey sand, and its resemblance to the Delgaty gravels is so close that no doubt has been entertained that they belong to the same period and formation.

In Central Buchan, along the top of a low, flat-backed ridge, which may be called the Buchan Ridge, extending from a little north of Ellon to Buchan Ness, south of Peterhead (see Fig. 2), there are great stretches of gravel, consisting mainly of water-worn flints, with a smaller proportion of white quartzite and other pebbles. As a rule these pebble beds are confined to the hill-tops at elevations of 350 feet and over, though numerous scattered flints are found at lower levels. These gravels of the Buchan Ridge differ in several respects from the Delgaty and Windy-hills gravels, but their similarity in essentials is so close that none of the previous observers has doubted that they belong to the same series of deposits.

Much attention has been given to the Buchan gravels by Aberdeenshire geologists. Christie¹ of Banff, was perhaps the first to give an account of the occurrence of chalk flints at Delgaty. In 1857 J. W. Salter² described the fossils from the chalk flints of the Buchan Ridge; to this description Ferguson of Kinmundy

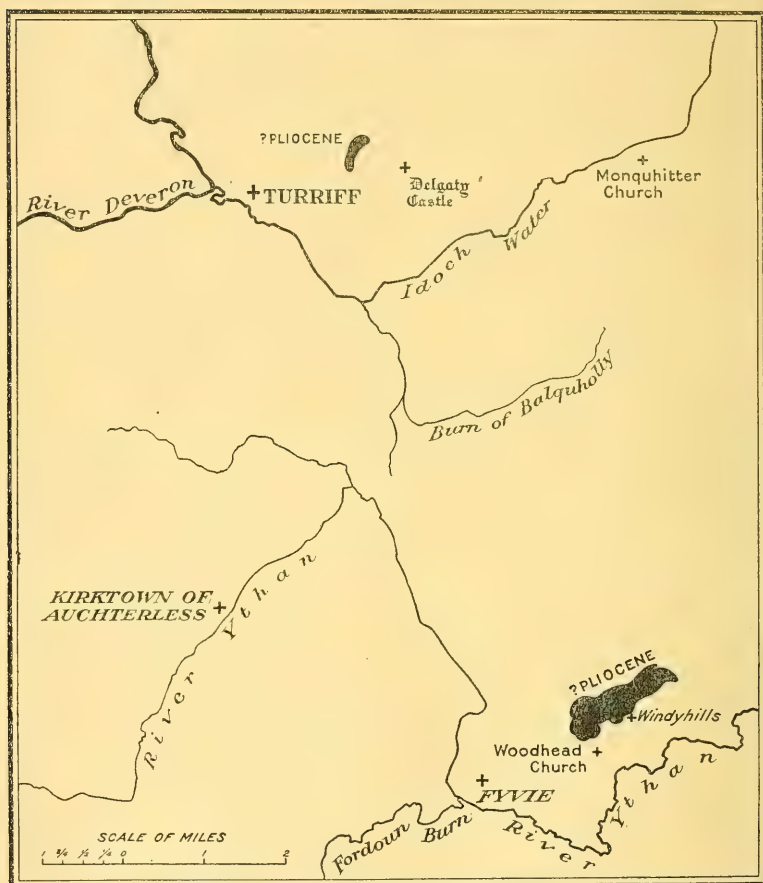


FIG. 1.—The Tertiary Gravels of Western Buchan.

appended a brief account of the distribution of the gravels. These deposits were studied especially by T. F. Jamieson of Ellon, who was intimately familiar with them throughout the area. In his first paper Jamieson described the gravels of the Buchan Ridge

¹ *Edinburgh New Philos. Journ.*, vol. x, 1831, p. 163.

² "On the Cretaceous Fossils of Aberdeenshire": *Quart. Journ. Geol. Soc.*, vol. xiii, 1857, p. 85.

and of Windy-hills.¹ The quartzite material at Windy-hills, he held, was derived from the underlying Highland Schists, and thus the gravels were local. He gave an outline of the Buchan Ridge along its length. Two years later he gave a sketch-map showing the distribution of the gravels in Buchan.² In 1865 he described the Delgaty deposits in some detail; he showed that the gravels were there covered by boulder-clay, and he grouped these gravels with those of Windy-hills and the Buchan Ridge as *Preglacial Traces*.³ In his last paper,⁴ which may be considered to express his final conclusions, Jamieson says:—

No remnant of pre-Glacial Tertiary deposits has hitherto been found in any part of the area (loc. cit., p. 13).

He now admitted that the material of the gravels is not of local origin, but rolled and long travelled. Most important is, however, his withdrawal from his position that these gravels were pre-glacial. He says:—

The Chalk flints . . . have . . . I suspect, been brought from the Moray Firth by . . . glacial agency. These Flints . . . may have been shed off along the southern border of one of the streams of ice which brought so great a quantity of other debris from the Moray Basin (loc. cit., p. 29).

With regard to the Delgaty section, Jamieson considered the boulder-clay which there covers the gravels to be due to "a recurrence of glaciation after the flints were laid down". Dr. Bremner⁵ has assembled the theories on the origin of these deposits, and has pointed out that a study of the quartzites would be most likely to lead to some definite result.

THE DELGATY OUTLIER.

At Delgaty the quartzite gravel covers a small area, only a quarter of a square mile, on the summit of a hill whose highest point is 399 feet. The base of the deposit may go down to near the 350 feet line. This hill is by no means the highest in the district, as there are others within a few miles of it rising to five or six hundred feet, but these hills have rock at their summits or are covered only by a thin skin of boulder-clay. The country rock is Macduff Slate of the Highland Schists, and red sandstones of the Middle or Orcadian Old Red, and the Delgaty gravel seems to rest on both of them in different parts of its area. Most of the outlier is covered by heath and wood, and there is no cultivation; the exposures in ditches and small overgrown pits are few and unsatisfactory. Fortunately, however, there is a gravel-pit which is being actively worked for

¹ "On the Pleistocene Deposits of Aberdeenshire": *Quart. Journ. Geol. Soc.*, vol. xiv, 1858, p. 528.

² *Quart. Journ. Geol. Soc.*, vol. xvi, 1860, p. 348.

³ "On the History of the Last Geological Changes in Scotland": *Quart. Journ. Geol. Soc.*, vol. xxi, 1865, p. 164.

⁴ "The Glacial Period in Aberdeenshire and the Southern Border of the Moray Firth": *Quart. Journ. Geol. Soc.*, vol. lxii, 1906, p. 13.

⁵ "Problems in the Glacial Geology of North-East Scotland": *Trans. Edin. Geol. Soc.*, vol. x, 1916, p. 344.

pebbles and clay and affords excellent sections, which give a very satisfactory idea of the composition and structure of the deposit. The working face of this pit is at present 8 feet high, and a small excavation in the floor of the pit reveals another foot or two of greyish-white sandy clay with pebbles. The base of the deposit is not anywhere exposed, and the thickness is consequently not known, but is presumably not less than 8 or 10 feet at this place.

The largest pebbles are about a foot in diameter, but the majority are from 2 to 5 inches. Most of them are very well rounded, and the whole deposit gives the impression that the pebbles have suffered much attrition and resemble those found on a sea-beach where wave action has been long continued. Quite nine-tenths of the pebbles are quartzite, of a very fine and pure variety, and all these are perfectly waterworn and rounded. The quartzites are by no means uniform in character. Most are fine-grained, granular or granulitic when examined with the lens, and contain very little felspar or mica. Others, however, have white mica flakes in thin shimmering films, and might be described as very fine-grained white quartz-schists. Still others have a more crystalline appearance, with large areas of clear glassy transparent quartz; no other minerals can be seen in the hand specimen.

Taking the quartzites as a whole, we may say that they have well-defined characters, which are: (a) their white colour; (b) their great purity; (c) their highly metamorphic and crystalline texture. They are certainly not derived from the local rocks, which, as already said, are Macduff Slates and Old Red Sandstone, and, furthermore, there are no known Aberdeenshire or Banffshire quartzites from which it seems possible they could have been derived. The Durn Hill and Cullen quartzites of Banffshire contain usually biotite and orthoclase, which give them a yellowish or pinkish colour when they are weathered. The quartzite and pebbly grit bands of the Macduff Slates are even more impure. Quartz veins are not common in N.E. Scotland, and most of the Delgaty pebbles are not derived from quartz veins. Altogether their origin is a problem on which little light has been thrown by the investigations of the geologists who have studied the rocks of the Eastern Highlands. Their lithological characters, however, are so well marked that it is seldom difficult to identify one of these pebbles in any of the superficial deposits of the district.

Less than one-tenth of the pebbles are flint, and these have the general character of flint pebbles wherever met with. They range up to 9 inches in diameter, and it is not seldom apparent that they are less perfectly rounded than the quartzites, though many of them are extremely waterworn. The flint is soft and brittle and cracks readily under the hammer; the broken faces have often a dull or waxy lustre; pure black flint is practically never seen, but grey, brown, red, and greenish colours are prevalent. Often the flints have a thick dull rind, which is grey or white, and sometimes

they are completely altered to a white mass resembling chalk in appearance. These changes indicate long continued weathering *in situ*, probably by percolating water.

The matrix of the pebble bed varies somewhat in composition and abundance, but is on the whole remarkably uniform. It may be described as a sandy clay always containing quartz grains, but, when wet, distinctly plastic and tough. There is little evidence of stratification in this pit, though the pebbles are not quite evenly distributed in the different layers; no proper bedding or current bedding can usually be seen, but streaks occur, often several feet in length, in which the sandy, clayey matrix is more than usually abundant. Such bedding as can be detected or suspected is horizontal. In the floor of the pit a small excavation had been made which we were informed was for the purpose of working a clayey stratum; this clay is found especially suitable for patching drains.

The working faces of the Delgaty Pit show very clearly that the pebble bed is covered by boulder-clay. This forms a layer, about 2 feet thick, of tough brownish sandy clay, with pebbles of many local rocks and some far-travelled stones derived from districts to the north-west. In the boulder-clay there are also some pebbles of quartzite from the gravel below, and these increase in numbers in the deeper parts of the boulder-clay. The base of the glacial deposit is fairly well marked by the change of colour. No disturbance of the gravels immediately beneath the boulder-clay is to be seen. In Lower Banffshire and neighbouring parts of Aberdeenshire we have found that the south-easterly drift is the earliest of which traces have been preserved.

In the wood, to the south-west of the gravel-pit, there is an old adit or tunnel in the Delgaty gravel, which had been formerly worked for a fine white, sharp sand, which, we are told, was used for scouring kitchen tables. The roof of this adit is formed by stiff brownish boulder-clay, held together by tree roots.

The real base of the Delgaty deposit is not exposed, and the deposit parts now being worked are quite as free from local rocks as any other part of the pebble bed.

THE WINDYHILLS OUTLIER.

This outlier is situated about 2 miles N.E. of Fyvie Church at the top of a low ridge at an elevation of about 400 feet. Perhaps half of the ridge is slightly over the 400 feet contour; the height of the margin of the deposits is not less than 360-370 feet. The underlying rocks are slate and knotted rocks of the Macduff and Fyvie groups of the N.E. Scottish metamorphic rocks; these contain bands of dark, impure, pebbly grit and quartzites in many places. The area covered by the pebble beds is about a mile and a half long in an E.N.E.-W.S.W. direction, and nearly half a mile in breadth. Heather and wood cover most of the ground, and cultivation stops practically at the margin of the gravels, but a

thin sprinkling of white pebbles in the surrounding fields shows that the deposit had once a more extensive distribution. This also makes it somewhat difficult to lay down a definite margin for the outlier on the map.

Many small pits have been opened in the pebble beds, principally with the object of obtaining road metal. Most of these pits are abandoned and overgrown, but there are three or four, widely scattered, still in use, and these furnish very good sections of the different parts of the mass. The largest pit is on the south side about the middle of the outlier, and this is probably the best exposure at present available for examination.

In this pit the working face is about 12 feet high. No boulder-clay is seen above the gravels. The deposit is in every respect very closely similar to that of Delgaty. The pebbles are perfectly rounded white quartzite and quartz-schist, with a small proportion of rather decomposed flints. Stratification is barely visible, though not completely absent, and there are streaks less rich in pebbles, 12 feet or more in length and somewhat lenticular in outline. The bedding is horizontal and undisturbed. The matrix is white or pale yellow, sometimes very rich in fine scales of white mica, but never so quartzose that when kneaded with the fingers it is not distinctly plastic and coherent. The peculiar characters of the quartzite pebbles of Delgaty which give that deposit such a marked individuality are all seen at Windy-hills, and there is no room for doubt that the pebble beds of these two localities, which are 8 miles apart, belong to the same series. Some of the pebbles in the Windy-hills pits are composed of black and blue quartz, others are of a decomposed whitish chert.

The other smaller pits at Windy-hills exhibit the same features, and do not merit a special description. They are all in pebbly beds and have been dug for pebbles; if there are sandy or clayey facies of the deposit they are not now being worked. An exception occurs, however, in a small pit near the west end of the outlier, on its south side; in this a brown clay was dug, full of slate fragments, and with comparatively few quartzite pebbles. It seems that we have here a part of the floor of slate on which the gravels rest, but the relations were not absolutely clear. A somewhat similar clay is visible in a small pit in the wood near by. Here large angular fragments of the underlying metamorphic rock are abundant in a brown clay. A small excavation with a pick showed that these rock fragments increase in number and size below, and it is probable that the underlying solid rock would be met with in a short distance. This bed, at any rate, contains no other rocks, and the fragments are angular. It does not seem likely to be a boulder-clay, though that possibility was not absolutely excluded.

With this possible exception, the base of the gravel is not visible. On the other hand, there was no good exposure showing overlying boulder-clay. Scattered erratics of local rocks may be found on the

surface of the outlier, and at its edges, especially on the north side, it seems to be overlapped by a thin skin of boulder-clay, but no good section proving this was observed. The evidence led us rather to believe that, like many of the adjacent hill-tops, Windyhills rises through the general spread of drift which mantles all the lower ground; the pre-glacial rocks thereby emerge at the surface.

From a consideration of the evidence detailed above, certain conclusions seem to be reasonably clear.

The Delgaty and Windyhills deposits exhibit peculiarities which demonstrate that they are essentially the same. They are parts of a deposit once probably continuous, the relics of an extensive sheet of gravels, sands, and clays, now almost wholly removed by denudation. It is very significant that they both occur at elevations of 360–400 feet; possibly they rest on an old platform, at any rate, they indicate submergence. It seems impossible to believe that they are stream gravels, as this would involve the former existence of a river system, of which no other traces can now be found. Almost certainly they are marine, and point to a general depression of this part of Scotland amounting to at least 400 feet.

As regards their age, only two points are certain. They are post-Cretaceous because they contain flints with chalk fossils; they are pre-glacial because they are covered by a boulder-clay which is, so far as we know, the earliest glacial deposit of the district. It seems safe, accordingly, to regard them as Tertiary.

All the available evidence points to the conclusion that these gravels are *in situ*, and almost undisturbed. No boulder-clay has been found beneath them, and the field evidence indicates that they rest immediately upon a platform of the older rocks. No veins of boulder-clay can be seen in the pits. We know of many large erratics that have been transported by ice without having their stratification greatly disturbed. But the nature and size of these gravel masses, their composition, the freedom from contortion, veining or intercalations of boulder-clay, and, above all, their remarkably uniform elevation above sea-level, point unmistakably to their interpretation as pre-glacial accumulations. The ice in this part of Aberdeenshire was perhaps comparatively thin and moved slowly. In many places the rotten rock below the boulder-clay shows that locally the ice had little excavating power. Many of the peculiar quartzite pebbles of Windyhills type are found in the glacial deposits, and show that much destruction of these beds took place; what remains is probably only a fragment which has escaped erosion.

GRAVELS OF THE BUCHAN RIDGE.

About 15 miles east of Windyhills there is a low flat-backed ridge that runs in an east-north-east direction from Whitestone Hill (530 feet) and Dudwick Hill (572 feet) to Stirling Hill and Buchan Ness (see Fig. 2). The flint gravels of this Buchan Ridge are very

well known, and have been described by Ferguson¹ and Jamieson.² The length of this ridge is about 10 miles, and it is not crossed by any important valley. Towards its eastern end the ridge is cut through by a narrow channel at North Aldie, which Dr. Bremner³ has shown to be a glacial overflow channel. It was not possible for us to make a minute examination of the whole of this ground, but we have visited a number of selected localities for the purposes of comparing these gravel deposits with those of Windyhills and Delgaty.

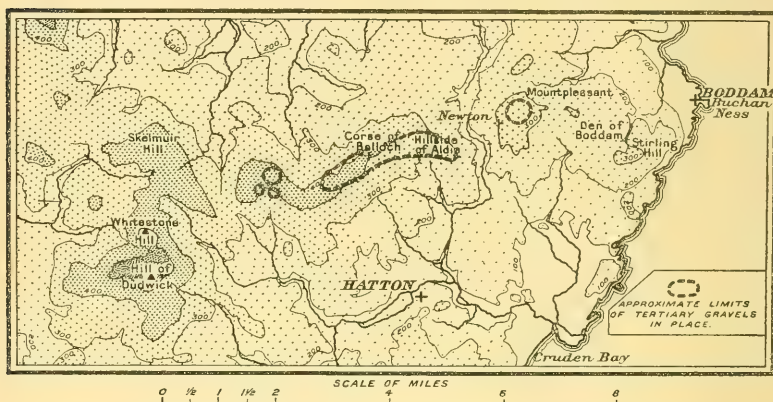


FIG. 2.—The Buchan Ridge. (Contour intervals of 100 feet; height indicated by depth of stippling.)

Towards the west end of the Ridge, about Dudwick Hill, quartz and flint pebbles are numerous in the soil of the fields and on the surface of the moors, but in the numerous shallow pits and drains which we inspected we saw nothing strictly comparable with the Windyhills deposit, and our conclusion was that beneath the soil there was a brownish boulder-clay, in which many flint and quartzite pebbles had been incorporated along with fragments of a large variety of local rocks. Further east, however, at the Corse of Balloch the superficial deposits are of different character. There is a great deal of thick peat in this area which is being extensively dug for fuel; immediately below the peat there are great sheets of gravel, apparently hardly disturbed. By far the greater part of the pebbles are well-rounded flints from 2 to 7 inches in diameter; these form about 80 per cent of the whole accumulation. The remaining pebbles are principally white quartzites, in which all the types characteristic of Windyhills and Delgaty are represented. The matrix is a whitish, or sometimes yellow, sandy clay, varying in

¹ Op. cit., *supra*.

² Op. cit., *supra*.

³ Op. cit., *supra*, p. 339.

character, but often extraordinarily like the clays that accompany the pebbles at Windyhills and Delgaty. On the surface with these pebbles occur fragments of slate, knotted schist, pebbly grit, granite, norite, hornfels, and other rocks of local derivation.

Unfortunately, the few natural exposures are very unsatisfactory and there are no pits at present being worked, as these pebbles are not used for road metal except on the farm roads. Consequently it is very difficult to obtain an exact idea of the composition and structure of the beds and their relations to the glacial and metamorphic rocks.

At the east end of the Corse of Balloch the peat gets thinner and cultivation encroaches on the area of gravel. At Hillside of Aldie traces of many shallow pits are visible. They are now nearly filled up, but we were told that they were sunk in search of a whitish clay which it was thought might be of value. Samples were examined, but it was reported that the material was not of economic value, though when the clay was washed it was possible to make clay pipes from it. Some of these pits are said to have been 10 to 12 feet deep in the gravel without reaching the subjacent rock. The whole surface of the ground is covered with rounded flints and quartzites, while pebbles of metamorphic rocks, deeply weathered, are numerous. We dug for about 3 feet into the gravel, and after a foot or so of peaty soil with iron pan, we reached, apparently undisturbed flint gravel embedded in yellow and whitish clayey sand. The pebbles were all very well rounded flint and quartzite; the flint had a thick white weathered crust, and when split open presented a waxy rotten appearance, like the flints at Windyhills.

At North Aldie it was possible to lay down the margin of the outlier with fair definiteness at 300 feet. Below that the pebbles were frequent in the soil, but were obviously transported down the slope. The deposit seemed to rest directly on the granite, which is here the country rock.

On the hill-top a mile or so further east, near Newton and Mountpleasant, the same phenomena are repeated. The lower slopes are granite and red boulder-clay, with mounds of glacial gravel and sand. As the 300-ft. contour is approached pebbles of flint and quartzite become very numerous in the fields, and above that level we pass suddenly on to beds of solid flint gravel capping the hill-tops. The field exposures indicate that this gravel has a nearly horizontal base resting upon a platform of granite, which shows minor irregularities in the form of low granite ridges emerging through the gravels. At least 90 per cent of the pebbles are flints from 2 to 7 inches in diameter, very well rounded, and deeply weathered. Pebbles a foot long are rare. Pure white quartzite pebbles are always present, though only in subordinate amount, and there are also local granite and schist pebbles. No stratification is visible. Large erratics of granite occur scattered over the ground, but we saw no section which established the relations

between the gravels and the boulder-clay. Most of this high ground, in fact, has little boulder-clay upon it, and probably any such deposit was originally thin and irregular in its distribution, and has been largely washed away by rain.

BODDAM DEN.

Towards the east end of the Buchan Ridge, about a mile and a half south-west of Buchan Ness and a mile north of Longhaven Station, a remarkable dry valley runs northwards across the granite hill. It is about 70 feet deep, and is occupied by only an insignificant streamlet; the floor of the valley is covered with peat, and its northern half is converted into a lake by means of an artificial dam. The course of the channel is at first north-east, then north, and it opens into flat country at each end.

As pointed out by Dr. Bremner,¹ it is undoubtedly a temporary glacial channel, by which melt water from ice sheets has escaped across the ridge. On both sides of the valley the slopes are steep, and on the west side are covered by flint gravel; on the east side also the gravel occurs, but towards the north end of the channel granite crops out on the eastern slope. Many small pits have been opened in the flint gravel, and on the banks of the reservoir the waves have cut good sections 10 feet or less in height. An examination of these shows that the gravel is not washed by stream action. There are no sandy layers, bedding, or current bedding such as are usual in materials deposited by glacial outwash, and it is entirely different in character and composition from the glacial gravels of this district. The surface characters are in some measure affected by rainwash and soil slips from above, but a small pit which we dug for about 2 feet at the north-east end of the dam exposed true flint gravel with yellowish and white fine plastic clayey sand as matrix, exactly similar to the deposits at Hillside of Aldie, Mountpleasant, Delgaty, and Windyhills described above. The pebbles are perhaps 90 per cent of flint; the remainder are the quartzites typical of these deposits. The characters, in fact, are those of undisturbed Tertiary beds.

A careful scrutiny of the exposure at the locality mentioned showed that this gravel is overlain by reddish tough boulder-clay, containing pink felspars and fragments of the Peterhead granite, which is the country rock. The gravel, we hold, is lying in a valley originally cut in the Tertiary platform, filled up by the flint gravel and re-excavated at the close of the glacial period. The coincidence seems remarkable, but it may be suggested that the presence of a gravel-filled hollow would probably determine the situation of the glacial overflow channel by the rapid deepening of any stream-course which happened to coincide with it. This patch of flint gravel apparently marks the eastern end of the Tertiary deposits preserved in this district.

¹ A. Bremner, *op. cit.*, p. 339.

CONCLUSIONS.

We have now described the gravels of Buchan, and have given our reasons for regarding them as relics of Tertiary beds of possible Pliocene age. If our contention is correct, the amount of erosion since Pliocene time is seen to be very great.¹

These Aberdeenshire deposits appear to rest on some kind of platform near the 400 feet contour. This at once recalls the well-known Pliocene platform of Cornwall, described by Clement Reid, Mr. George Barrow, and others. Further, there is a great likeness in position and stratigraphical relations between the Aberdeenshire gravels and those from near Berkhamstead, described by Mr. C. T. Gilbert and Mr. Barrow.² It appears likely, then, that in this distant corner of N.E. Scotland there are traces of Tertiary features and deposits similar to those of Cornwall and Hertfordshire.

The contents of the Buchan gravels are dominantly quartzite in the west and flint in the east parts of the outcrops. With regard to the source of the materials, few definite statements can yet be made. The quartzite is certainly not derived from any Aberdeenshire or Banffshire quartzite. The only rock known to us which is at all like it is the Scarabin quartzite in the county of Caithness. The confirmation of this suggestion requires a more detailed petrological and field study than we have yet been able to give.

¹ Cf. George Barrow, *Proc. Geol. Assoc.*, vol. xxx, 1919, p. 36 et seq.

² *Quart. Journ. Geol. Soc.*, vol. lxxv, 1919, p. 32.

REVIEWS.

DEVONIAN FLORAS: A STUDY OF THE ORIGIN OF CORMOPHYTA.

By E. A. NEWELL ARBER, M.A., Sc.D., with a preface by
D. H. Scott, M.A., LL.D., Ph.D., F.R.S. Cambridge, 1921.
Price 17s. 6d. net.

IN forming an estimate of this book it is important to take into account the circumstances in which it was published. Dr. Arber did not live to complete the work; he left it in the state of "a first draft which he was never able to revise". Had he lived to read the later memoirs by Dr. Kidston and Professor Lang on the Rhynie Devonian plants, he would undoubtedly have modified some of his conclusions. Mrs. Arber, who revised the MS., says in a prefatory note: "I do not think that anything in his scientific life gave him a keener intellectual pleasure than the development of the idea—the *Leitmotiv* of the present essay—that the transition from the Algæ to the Vascular Cryptogams no longer remains a matter of pure conjecture, but that, in the fossil plants of the Devonian rocks, we witness, actually occurring beneath our eyes, the passage from the Thallophyta to the Cormophyta." In the preface Dr. Scott writes: "We stand at a new point of departure in our theories of the evolution of the higher plants. Arber was one of the first to realize this, and his memoir represents a bold and vigorous effort to grapple with the problems as they presented themselves to him at the dawn of a new epoch." The publication after Dr. Arber's death of Dr. A. H. Church's already well-known essay on "Thalassiophyta and the Subaerial Transmigration", in which, with considerable ability and force, arguments are adduced in favour of the origin of land plants from complex types of seaweeds, has directed the attention of botanists and geologists to problems of evolution having much in common with those discussed in the *Devonian Floras*. These considerations, whether or not readers agree with the views expressed, furnish arguments in support of the decision to preserve in a permanent form the opinions of one of the most devoted students of palæobotany who ever lived.

The volume is attractively printed and well illustrated, and an admirable portrait of the author is reproduced as a frontispiece by permission of the Editors of the GEOLOGICAL MAGAZINE. During the Devonian there were two distinct terrestrial floras, an earlier *Psilophyton* flora and a later *Archæopteris* flora, differing more widely from one another than the Upper Devonian flora differed from that of the Lower Carboniferous period. A summary is given of the geological age of the several Devonian floras described in a widely scattered literature; the inclusion of all the Old Red Sandstone plants from Caithness in the Upper Devonian flora is surely incorrect. The age assigned to the Caithness beds is not in accordance with the views expressed in the Survey Memoir which Dr. Arber

quotes. Dr. Arber believed that the recently discovered genus *Rhynia*, founded on petrified specimens from Aberdeenshire, is identical with Dawson's *Psilophyton*. It is certain that the two are very closely allied, but their generic identity has hardly been established. It is contended that *Psilophyton* and other Middle and Lower Devonian plants, despite the possession of a well-developed water-conducting strand of xylem, were Thallophyta and anatomically half-way between Thallophyta and Pteridophyta; they are assigned to a new group, the Procormophyta. The much more highly differentiated Upper Devonian plants, grouped under Sphenopsida, Palaeophyllades, Pteropsida, and Lycopsidea, are believed to represent distinct lines of evolution from Algal ancestors; the development of this view is an important part of Dr. Arber's thesis.

That *Psilophyton* and its associates were in some respects primitive is practically certain, but to regard them rather as Thallophytes than Pteridophytes is in effect to dispense with the recognized distinctions between these two classes. It may be that as we learn more about the oldest terrestrial plants we shall realize the futility of class distinctions based on existing types; class labels are, after all, of secondary importance in comparison with the wider question of the origin of the vascular plants, and it is from this broader standpoint of evolution that we should weigh the arguments presented by Dr. Arber.

A. C. SEWARD.

PALÆOGEOGRAPHY AND DIASTROPHISM IN THE ATLANTIC-ARCTIC REGION DURING PALÆOZOIC TIME. By OLAF HOLTEDAHL. Amer. Journ. Sci., vol. xlix, No. 289. January, 1920.

IN studies of palæophysiography the Americans have been recently to the fore, and a summary of their work has appeared in *Outlines of Geological History, with special reference to North America*, by Bailey Willis & Rollin D. Salisbury, published in 1910.

In the present paper Dr. Hortedahl carries this work into the European region which most nearly approaches the American continent, and discusses the distribution of land and sea and the diastrophic changes which have occurred from early Cambrian times to the end of the Carboniferous period. Incidentally he remarks that "it will certainly be hopeless for the advocates of permanency of the oceanic basins to apply the theory to the Norwegian sea".

The construction of palæophysiographical maps is a dangerous thing, and study of these maps often shows the striking dissimilarity of supposed ancient land-masses from any existing land-area. The narrow tract of land represented in this paper as extending from Scotland to Scandinavia in Ordovician times is an example of this. But the author has taken into account the character and distribution of the Palæozoic rocks of the area under consideration in far greater

detail than previous restorers of Palæozoic lands in Northern Europe, and has accordingly made a marked advance in this study. All students of the Palæozoic rocks should read his paper.

J. E. M.

NOTES ON GEOLOGICAL MAP-READING. By A. HARKER. 63 pp. Heffer & Sons. Cambridge. Price 3s. 6d.

THE very modest title of this book does less than justice to its contents, for in spite of its brevity it manages to cover most of the ground in a thorough way, and is likely to find a wide distribution as a class book. The author begins with a very clear exposition of the meaning of topographical maps, and the way in which they serve as the basis for geological maps, taking the 6 in. Ordnance map as a type. He goes on to consider the simpler forms of geological maps and the various operations required in their interpretation. The argument passes on to unconformable series and then to faults. Folded strata of different degrees of complexity then receive attention, and a systematic method of constructing sections is described. The point is well emphasized that sections are merely illustrations, and cannot take the place of the map itself, and that the student must be able to interpret a map without having to reduce it to sections. Cases of all reasonable complexity are actually illustrated and explained.

One can find nothing but praise for the order of treatment and for the general lucidity of the explanations. The method of using gradients for dip problems instead of vertical angles will be welcomed by teachers, especially those who are accustomed to use graphic constructions dependent on the accuracy of a rough protractor.

On the other hand, the figures call for criticism. From the student's point of view they are far from clear, and one or two are liable to confuse rather than to aid the text, as, for instance, the diagram showing the relations between strike, slope, and outcrop (p. 17). One feels that the book would have been much improved by a few block diagrams in illustration of the maps or of imaginary types of landscape. The maps themselves are models of clearness, but students will find it advisable to colour them before attempting to interpret them.

All geologists will welcome this small book, but will wish that it had been expanded into a manual and were illustrated with more care.

SOUTHERN RHODESIA: THE GEOLOGY OF THE ENTERPRISE MINERAL BELT. (Bull. No. 7.) By H. B. MAUFE. pp. 52 and map. 1920.

THE chief mining camp of the area examined is Arcturus, situated 22 miles due east of Salisbury, and at an elevation of 4,600 feet. Highly folded schistose greenstones and sediments form a complex (the Basement Schists), almost surrounded by granite, of which there

are several phases and dyke-like modifications. An even-grained dolerite, with chilled margins, forms sills, dykes, and stocks among both the schists and the granitic rocks, and is considered to be of the same age as the dolerite of the Karroo Beds, or possibly, as that of the "great dyke" of Waterberg age. Outliers of Kalahari Ironstone (Upper Cretaceous) are mapped on the higher land near the Salisbury Water Works.

The greenstone schists were originally volcanic rocks and range from intermediate to ultra-basic, the commonest being a fine-grained epidiorite derived from dolerite or basalt. The ultra-basic types are now represented by serpentine, and talc- and tremolite-schists. The present structure and mineralogical constitution is due to regional metamorphism accompanied by high temperature without much shear. Evidence of contact alteration by the granite is confined to minor changes quite near the mass. The sediments which are folded in with the greenstones comprise banded ironstone, black phyllite, and limestone. The banded ironstone is a quartzite with layers of varying thickness containing abundant magnetite, originally a ferruginous sandstone. It has been worked for iron-ore by the natives. The phyllite is dark chiasolite slate grading into mica schist. The limestones are coarsely crystalline and contain green amphibole as a metamorphic product.

The granitic rocks show a great variation in form and composition, but they are all of about the same age. They occur as bathyliths, stocks and vein-like intrusions or irregular bodies of aplite and pegmatite, the last being greisenized and stanniferous. Oligoclase is the principal felspar.

A variable series of felsites, quartz-sericite-schists, and ultra-acid intrusives of the same age as, or in part penetrating, the granite, occur as irregular bodies or in dyke-like forms. They possess a dominant cleavage in the direction of flow-structure, due to the orientation of the biotite and sericitic mica.

The Kalahari Ironstone is an æolian deposit, consisting largely of polished quartz-grains, and near the base of amygdules of chalcedony from Karroo basalts. The iron-ore near the base is in the form of sandy nodules surrounded by hard crusts of limonite. It is thought that the iron may have been derived from wind-borne chalybite which has been deposited among the sand and subsequently carried down and deposited as limonite.

The gold reefs are classified as "Schist Reefs" and "Quartz Reefs". The latter are fissure veins, either (*a*) crossing the Basement Schists, as in the case of the Perseverance Reef, or (*b*) roughly parallel with the planes of cleavage. Gold in the quartz veins is seen to occupy rusty cavities formerly containing auriferous pyrites and possibly arsenical pyrites. Below the zone of oxidized ores the gold occurs in auriferous pyrites, and is termed "refractory ore", owing to its not being free milling.

The "Schist Reefs" are more abundant and are replacements or

impregnations along belts of joints in the Basement Schists. The chief introductions are auriferous pyrites, arsenical pyrites, and silica. These may be termed metasomatic deposits, in which the epidiorite is altered to a coarsely crystalline biotite-actinolite schist with auriferous sulphides. The outer sides of this rock merge gradually into the normal epidiorite. In some cases there is a thin quartz vein or succession of quartz lenses along the main joint or fissure, and gold may occur in these as well as in the schists. There appears to be a striking connexion between these veins and the acid and ultra-acid felsites mentioned above.

The author has described the physical features of the district in some detail and with remarkable clearness.

EVERY BOY'S BOOK OF GEOLOGY: AN INTRODUCTORY GUIDE TO THE STUDY OF THE ROCKS, MINERALS, AND FOSSILS OF THE BRITISH ISLES. By ARTHUR E. TRUEMAN and W. PERCIVAL WESTELL. pp. 1-315. R.T.S., n.d. [1920]. Price 6s. net.

THE aim of this work is to arouse in young people an interest in the study of geology. The authors have made a judicious selection of the more attractive parts of the subject, and the book is written in plain and simple language, which should make it suitable for juvenile readers. The illustrations are numerous, and although sometimes a little crude, they serve the fundamental purpose of making the text easily intelligible. There is no connected account of stratigraphical geology, but the nature of the geological record is well shown by the chapters on "Coal and Coal Mining" and "The Great Ice Age".

SPECIAL REPORTS ON THE MINERAL RESOURCES OF GREAT BRITAIN. Vol XII, IRON ORES (CONTD.): BEDDED ORES OF THE LIAS, OOLITES, AND LATER FORMATIONS IN ENGLAND. By G. W. LAMPLUGH, F.R.S., C. B. WEDD, B.A., and J. PRINGLE. Mem. Geol. Survey. pp. iv + 240, with 8 plates and 12 figures. 1920. Price 12s. 6d. net.

THE publication of this memoir has been anticipated with much interest by all those concerned with the geology of iron-ores, since it contains an account of what are under modern conditions by far the most important producing areas in this country. Of late years the Jurassic system has been responsible for almost exactly 80 per cent of the total output of iron-ore in this country, a state of affairs which is mainly due to the recent developments in the manufacture of basic steel from phosphoric ores. This is precisely the same economic factor as led to the great prosperity of the German steel industry, which was almost entirely based on the phosphoric ores of Lorraine. During the War the production of basic steel in England showed a steady increase, although the total production of iron-ore even fell off a little. The great demand for

steel for munition purposes led to a great expansion of iron-mining, especially in the midland counties, the largest producers being the Frodingham district in North Lincolnshire, the Marlstone ores of the Banbury region, and the Northamptonshire ironstone of the Inferior Oolite. All of these are quarried almost exclusively in open-cast workings, and the general introduction of mechanical operation did much to counteract the labour difficulties that so greatly hampered the underground mining in Cleveland. By an elaborate and effective system of control, the Ministry of Munitions were able to arrange for the regular delivery at the furnaces of mixtures of ore from different sources adapted to the production of the types of iron and steel most required at the time. The history of this organization has been admirably written by Dr. Hatch in a publication reviewed in these columns some months ago.

The memoir now under review contains a very detailed and remarkably clear account of the geological relations and character of the deposits found in each district, containing a summary of all the information available, with abundant references to the earlier literature and illustrated by a great number of analyses or ores, both of ancient and modern date. There are also many tables of production and estimates of reserves. Not only are the actual workings now in operation described, but much information is included as to areas where ironstone was formerly worked and occurrences of ironstone, not hitherto exploited, which may be of value in the future. It must be confessed that the latter class do not seem to be of much promise, at any rate, until a very radical change takes place in economic conditions.

With regard to the interesting question of the origin of oolitic ironstones not very much is said, but the authors, as well as Sir A. Strahan in the preface, seem to incline towards the replacement theory. This is a difficult subject, and cannot be discussed here, but the detailed and careful work of A. O. Hayes on the Wabana Iron-ore of Newfoundland, and that of other American authors, seems to bring forward a good case for the primary origin of, at any rate, the green oolitic ores rich in silicates of iron. It is, however, very difficult to see how a rich and varied fauna of ordinary marine type managed to flourish in a ferruginous solution strong enough to lead to direct precipitation of ferrous silicates, which must almost of necessity require reducing conditions and absence of free oxygen. In this regard the large shells of *Cardinia* covered with a layer of green silicate found in the lower part of the Frodingham ironstone are of much interest.

We congratulate the late director and the officers of the Geological Survey on the completion of this exceedingly valuable series of monographs on the iron-ore resources of this country.

R. H. R.

BIBLIOTHECA CHEMICO-MATHEMATICA. CATALOGUE OF WORKS IN MANY TONGUES ON EXACT AND APPLIED SCIENCE. Two Volumes. Sotheran, 1921. £3 3s.

THIS work is the result of fourteen years' labour. It is probably the finest historical catalogue of science published in any country, containing, as it does, over 17,000 items, with current prices, bibliographical particulars, and many biographical and historical references. The reproductions of old illustrations, of which there are 127, are particularly fascinating, especially those of early ideas for steam engines, methods for "perpetuum mobile", etc.

It is certainly a work which should be found in every scientific and reference library.

THE ORE DEPOSITS OF UTAH. By B. S. BUTLER, G. F. LOUGHLIN, V. C. HEIKES, and others. Professional Paper 111, U.S. Geol. Survey. pp. 672, with 57 plates and 74 text-figures. 1920.

FROM the vast mass of geological literature, with an economic bearing, issued by the United States Survey, it is difficult and somewhat invidious to select individual publications for detailed notice. Nevertheless, no excuse is required for drawing the attention of British geologists to the admirable summary of the geology of Utah provided in the first hundred pages of this memoir. This State must always be classical ground in the history of physio-graphical and structural geology, and may be regarded as the typical example of its class; likewise it has been exhaustively studied by so many famous geologists, of whom we shall only mention G. K. Gilbert, whose memoir on the Geology of the Henry Mountains is fundamental on the physiographic and structural sides of the science. It is, therefore, highly valuable to have in a condensed form the results of these earlier labours as illuminated by more recent investigations.

The remaining, and by far the larger, part of the memoir is occupied by a detailed account of the economic products of the State, with a detailed description of the geology of each mining area.

THE LIMESTONE RESOURCES OF THE UNION. Vol. II: THE LIMESTONES OF NATAL, CAPE AND ORANGE FREE STATE PROVINCES. By W. WYBERGH, Geological Survey of the Union of South Africa. pp. 149, with 2 figures. 1920.

THE first part of this publication was reviewed in the GEOLOGICAL MAGAZINE, 1918, p. 522. The present and concluding part gives a full and detailed description of all the known occurrences of calcareous rocks likely to be of commercial importance in the three southern provinces of the Union, except the dolomitic marbles of Port Shepstone, which were fully described in the earlier volume. Except for this occurrence, Natal is sparingly supplied with limestones,

and little exploitation has been done. On the other hand, calcareous deposits of many kinds are widely distributed in the Cape Province, except in the extreme east. They are of many ages, ranging from pre-Cambrian to Tertiary and Recent, and therefore comprise many different types. They are, however, not abundant in the widely spread Cape and Karroo systems. The Orange Free State possesses abundant resources, especially of surface limestones, an extremely interesting rock type which is widely spread in South Africa, appearing to be due to evaporation of calcareous solutions ascending by capillarity from lime-bearing rocks undergoing decomposition below ground. Its origin is therefore analogous to that of the still more remarkable surface quartzites of that country.

The work of compiling this memoir has been carried out with great care, and it contains a large amount of valuable and interesting information.

AGRICULTURAL GEOLOGY. By F. V. EMERSON, Ph.D. pp. xviii + 319, with 270 figures. New York: John Wiley & Sons, Inc.; London: Chapman & Hall, Ltd. 1920. Price 16s. 6d. net.

THE late Professor Emerson, whose untimely death is much lamented, was Professor of Geology at the Louisiana State University, and also in charge of the geological side of the work of the State Experiment Station. This book is the fruit of his experience in teaching geology to agricultural students. It begins with the general characters of minerals and rocks, then passes on to the detailed consideration of weathering in all its forms, the action of water in erosion, transport, and deposition, and alluvial deposits, with a very full account of glaciation and the formation of lakes. The characters of coastal plains are discussed, while the final chapters deal with mineral fertilizers, the soil regions of the United States and historical geology; the last is compressed into less than six pages, and might well have been omitted, as the value of so brief a sketch as this is problematical. As might be expected, the treatment of the subject is distinctively American, hardly any reference being found to types of soil outside of the United States, although very brief accounts are given of the Stassfurt potash deposits and of the Chilean nitrate of soda. The middle chapters of the book, quite apart from their value as a treatise on the origin of the soil, form a very interesting small textbook of American physical geology, and they are illustrated by a large number of good figures, many of which, however, are reproduced on too small a scale to be as effective as they deserve. The processes of conversion of rock into soil are well described and illustrated by some very well-contrived diagrams.

SKÅNES DALMANITESSKIFER, EN STRANDBILDNING. By G. TROEDSSON. Geol. Fören. Forh., vol. xlii, 1920. pp. 265-90.

THE *Dalmanites* shales of Scania, formerly called the Brachiopod shales, are the local representative of the Ashgillian series. The chief object of this memoir is to show that they belong to a

shallow-water type, laid down near the coast-line of the old Swedish highlands, this coast-line being approximately determined by an ancient north-west-south-east fault-system. The middle part of the sandy shales always includes one or two beds containing comparatively large quartz-grains and occasionally rounded pebbles of sandstone up to 10 mm. in diameter. Pyrites, phosphorite, and calcareous layers are common, the two first especially in the coarser portions. An abnormal occurrence at Röstånga is of much interest, since here there is repetition of the series, the upper sequence being of much more shallow-water character than the lower; that is, a shallow-water facies has been thrust over strata of a deeper-water facies. This the author attributes to submarine land-slipping, which, he says, is a frequent cause of the occurrence of contorted layers, interbedded with horizontally bedded ones. He estimates that this process is possible with a slope of the sea-floor as low as 4 to 6 degrees. This striking conception is somewhat inadequately treated in the German summary. The full text describes the formation of a peculiar breccia or conglomerate due to the slipping.

On account of the marked decrease in the depth of the water at the beginning of this stage, the old fauna almost completely disappeared, and only a few new forms came in. The presence of *Climacograptus normalis* serves to correlate the beds with British strata, but, on the whole, the fauna is mainly endemic. The presence of numerous ostracods and thin-shelled lamellibranchs suggests lagoon conditions.

REPORTS AND PROCEEDINGS.

MINERALOGICAL SOCIETY.

March 22.—Dr. A. E. H. Tutton, F.R.S., in the chair.

Professor H. Hilton: "On the Vibrations of a Crystalline Medium." The paper attempts to give an indication of the kind of vibrations which the molecules of a crystal may be expected to make about their positions of equilibrium. The case of an orthorhombic crystal in the form of a rectangular parallelepiped is considered in detail, and the normal modes of the molecular motion completely determined.

Professor R. Ōhashi: "Augite from Nishigatake, Japan." The crystals have been detached from basalt by natural weathering. Sp. gr. is 3.338 at 4° C. The prism angle agrees with that of diopside but that of the pyramid does not. Etched figures show that the crystal belongs to the holosymmetric class. $a = 1.6859$, $\beta = 1.6917$, $\gamma = 1.7105$, $2v = 58^\circ 25'$. Extinction angle on (010) $\doteq 41.6^\circ$. The chemical composition is SiO_2 51.37, Al_2O_3 5.24, Fe_2O_3 2.02, FeO 2.96, CaO 21.58, MgO 16.94, TiO_2 0.58. Both the optical

properties and chemical composition show that in this augite the diopside molecule predominates.

Dr. G. T. Prior: "On the Chemical Composition of the Adare and Ensishheim Meteorites." Determination of the amount and composition of the nickeliferous iron in these meteorites had shown that Adare contained 18 per cent in which $\text{Fe}:\text{Ni} = 11$, and Ensishheim 3 in which $\text{Fe}:\text{Ni} = 3\frac{1}{2}$. Analyses were made of the unattracted material in order to determine how far they supported the idea that in meteoric stones the ratio of MgO to FeO in the magnesium silicates varied directly with the ratio of Fe to Ni in the nickel-iron. The results showed that the ratios of MgO to FeO in the olivine and pyroxene respectively were about 4 and 5 for Adare and $2\frac{1}{2}$ and 3 for Ensishheim.

Mr. W. Barlow exhibited models to represent the atomic structure of calcite and aragonite.

EDINBURGH GEOLOGICAL SOCIETY.

February 16, 1921.—Mr. E. B. Bailey, M.C., B.A., F.G.S., F.R.S.E., President, in the chair.

1. "Recent Contributions to the Geology of Spitsbergen." By Dr. Robert Campbell, F.G.S.

After indicating the nature of the pioneer work done during the nineteenth century, Dr. Campbell outlined the results arrived at by Nathorst in his monograph on the geology of Bear Island, Spitsbergen, and King Karl's Land, published in 1910. During the past decade notable advances, he said, had been made in our knowledge of Spitsbergen geology, particularly by Hoel and Høltedahl. It had been known that the "Archæan" of the north-west belonged to the Hecla Hook system. A strong case had been made, too, for regarding the Hecla Hook series as of Cambrian-Ordovician age, similar rocks in Bear Island having yielded a fauna of American facies resembling that found in the Durness limestones of North-western Scotland and in the Beekmantown limestone of North America. The Red Bay series of the North coast had yielded fossils suggestive of Downtonian age, and the remainder of the Devonian had been divided into three groups, comparable with the Caledonian, Orcadian, and Upper Old Red Sandstone of Scotland. They have yielded the same characteristic fishes, but, unlike their Scottish equivalents, they carried also, according to Høltedahl, several forms of marine lamellibranchs. The Carboniferous rocks were of interest because of the occurrence of coal seams in the Culm, and had been mapped in considerable detail by the geologists of various Norwegian, Swedish, and Scottish expeditions. Much new information of stratigraphical and palæontological value had been obtained. It had been established that great overthrusting movements had taken place—probably in Tertiary times—along the line of the fault that separated the Hecla Hook rocks of the west coast from the younger rocks to

the east. Of much interest, too, was the discovery at Bock Bay of a volcano, which had been active during the great Ice Age, and the occurrence of numerous hot springs, which had built up beautiful basins of carbonate of lime.

2. "Exhibition of Specimens and Fossils from Lowe Sound and Axel Island." By H. M. Cadell, B.Sc., F.R.S.E., J.P., D.L., of Grange, Linlithgow.

LIVERPOOL GEOLOGICAL SOCIETY.

March 8, 1921.—W. T. Walker, Esq., B.Sc., F.G.S., President, in the chair.

The following paper was read: "Notes on the Geology of Lingdale." By F. T. Maidwell, F.G.S.

Lingdale was defined as the western slope of a wide, shallow valley-head, ranging from the high ground between the Uplands and the southern end of Bidston Hill in a north-easterly direction to the western side of Birkenhead Park. Many small exposures of what is presumably Lower Keuper Sandstone occur in the road-sides and lanes, as well as in the old quarries at Flaybrick Hill. The dip of the rocks is generally to the north-east, but the district is much cut up by faults ranging chiefly north and south, although there are some east and west faults which change the direction and amount of the dip, and bring in the Waterstones to the south of Howbeck Road. Detailed descriptions and measurements were given of the succession of strata in two instructive sections, where the junction of Yellow Upper Bunter Sandstone and the Keuper Basement beds is displayed.

CORNISH INSTITUTE OF ENGINEERS.

April 2, 1921.

"Ore Deposits of Igneous Origin." By R. H. Rastall, Sc.D., M.Inst.M.M., F.G.S.

Ore deposits of igneous origin can be divided into two main groups: those associated with acid intrusions usually take the form of veins or lodes. They belong to the latest phases of cooling and tend to concentrate in the upper parts of the intrusive masses; furthermore, they commonly accompany pneumatolytic phenomena. The ore-bodies associated with the basic rocks, on the other hand, usually separate at an early stage, the intrusion often splitting into two immiscible liquid phases, as shown by Vogt in the case of the sulphides. The metalliferous phase, being the heavier, sinks to the bottom, although, owing to imperfect equilibrium and viscosity, this sinking is often incomplete and segregations of ore may be found at any level. An unusual type is afforded by the magmatic iron ores of Swedish Lapland, where concentration has been effected by sinking in an acid intrusion. The association of chromite and

platinum is characteristic of ultrabasic rocks. In the basic intrusions there is little or no vein-formation, the ore-bodies being basal or marginal, sometimes disseminated more or less uniformly, and pneumatolysis plays little or no part in ore-formation.

GEOLOGISTS' ASSOCIATION.

Friday, April 8, 1921.

"The Influence of Geology and Topography on the Growth of London." By C. E. N. Bromehead, B.A., F.G.S.

A new geological map of London, showing the "buried streams", with short accounts of the streams. The site of London, with reasons for its selection. Roman London. The site of Westminster, at the first ford. The Roman Roads round London. The growth of London and Westminster and the connecting link along the "Strand". To the end of mediaeval times the necessity for a defensible position limited the growth. The great expansion in the seventeenth century brought to an end by the question of water supply. The supply from the terrace-gravels and the means taken to supplement it. Growth ceases until beginning of nineteenth century. A few of the ways in which Geology affects London to-day.

CORRESPONDENCE.

GEOLOGY OF THE NINGI HILLS.

SIR,—As Major Williams in his letter in the February number handsomely disclaims all intention of being controversial, I am content to leave the matter where it now stands. My attitude towards the larger questions which Major Williams has raised will be made clear in a forthcoming publication of the Geological Survey of Nigeria, and I need not, therefore, transgress upon your space. May I say, however, that I have no recollection of ever stating—and certainly not in my last letter—that tinstone is or can be found only in the younger granites. That is quite a different matter from the question of its origin.

J. D. FALCONER.

JOS, NIGERIA, N.P.
5th March, 1921.

"LISSONS."

SIR,—Mr. Upton's explanation of the continuous rise of air from "lissons", quoted in the article under the above head by Mr. L. Richardson in the March number of the GEOLOGICAL MAGAZINE, does not appear quite satisfactory. Surely the barometric pressure into the ground would be able to act more readily in a downward direction through the fissures than through the interstices of the country rock.

The following alternative explanation is suggested. The normal temperature lapse rate in the lower layers of the atmosphere is -1° F. per 300 feet, whilst the adiabatic lapse rate is -1° F. per 172 feet. When the lapse rate in the atmosphere exceeds the latter quantity, a condition of unstable equilibrium ensues, and convection immediately sets in to restore equilibrium. Now, assuming the temperature gradient in the Oolites at Stroud to be -1° F. per 60 feet measured in the same direction as that of the atmosphere, i.e. in an upward direction; and further assuming that the air in a fissure remains sufficiently long in contact with the country rock to take up its temperature (a period of a few minutes would suffice), it would appear that the column of air in the fissure would be in an exceedingly unstable condition and would at once tend to rise to the surface. This effect should be most noticeable during the winter, when no inversion in the lapse rate is likely to occur in the subsoil, as is the case in the summer.

No doubt the barometric tendency materially affects the velocity of the current—a negative tendency (i.e. when pressure is decreasing) should cause an increase; by analogy with the effect produced on fire-damp evolution in coal mines on such occasions.

The velocity of the current might temporarily be increased during the winter season by the rise in the level of the water-table subsequent to heavy rains, causing the upward displacement of air.

NORMAN L. SILVESTER.

BEDFORD COLLEGE, REGENT'S PARK, N.W.

April, 1921.

CORRELATION OF THE MEADFOOT AND SIEGENIAN BEDS.

SIR,—I read with interest, in the April number of the GEOLOGICAL MAGAZINE Dr. E. Asselberghs' remarks on the above subject. On p. 167 he says:—

"Later, other fossiliferous localities were discovered. Several lists of fossils have been published, but a great number of the identifications, based only on the already old descriptions of Phillips and Davidson, are doubtful."

He then quotes from a list of mine (GEOL. MAG., 1909, pp. 133–4) as an instance. I should like to say I did not venture to identify any of the fossils given in my list. I submitted them first to Upfield Green (who was working with me at the time) and afterwards to W. A. E. Ussher. They were carefully examined by both, as was my list before publication. I gather from subsequent remarks that Dr. Asselberghs has confidence in the opinion of these authorities. Referring to the Devonian rocks of North Devon, Dr. Asselberghs says: "The stratigraphical succession is less known than in the South." I was not aware of this.

J. G. HAMLING.

THE CLOSE, BARNSTAPLE.

THE GLACIATION OF IRELAND.

SIR,—The discrepancies between the directions of ice movements shown in Professor Kendall's enlargement of Mr. Wright's map, and in that by myself (*Phil. Trans.*, vol. 210 B, p. 143) are due in the case of the four arrows across the Shannon Valley, near Lough Derg, to Professor Kendall having trusted simply to orientation, whereas my arrows were drawn in regard to the topography on Mr. Wright's map. For example, Mr. Wright's southern arrow across Lough Derg continues up the Nenagh Valley to the south of the river and ends there; so does mine; whereas Professor Kendall's is continued right across the mountain Slieve Kimalto. Mr. Wright's next line crosses Lough Derg further north and bends round into the valley of the Nenagh and reaches it at the bend, where it is joined by the Ollatrim; and I ended it there to avoid carrying it into the upper Nenagh. The northernmost of the four lines begins on the lower Bunowen River and crosses the Shannon at its confluence with the Little Brosna. My line passes through both points, but omitted the further continuation, that being less clear and not affecting its relations to the Eskers.

The glaring discrepancy in the north-western corner of Professor Kendall's map, near Clew Bay, is due to its omission of one set of Mr. Wright's lines. Mr. Wright's map shows two movements in Mayo crossing one another at or nearly at right angles. Professor Kendall has left out one series, thereby suggesting that the two arrows on my map showing a northward flow were inserted by mistake. I would ask anyone interested to compare Professor Kendall's enlargement with Mr. Wright's original map (*Quaternary Ice Age*, 1914, p. 49). Professor Kendall's photographic apparatus has powers of selection which merit the censure expressed in the last paragraph of his letter.

J. W. GREGORY.

THE STADDON GRITS.

SIR,—I was much interested in the communication to your April issue by Dr. Asselberghs on the correlation between the Meadfoots of Devonshire and the Siegenian of the Ardennes, which forms an important contribution to our knowledge of the subject. He, however, unintentionally I am sure, misrepresents me in suggesting that I have referred all the beds usually included in the Staddon Grits to the *Cultrijugatus* zone. As a matter of fact, I expressly state (*Hand. d. reg. Geol., British Isles*, 1917, p. 106, note) that rocks lithologically similar to the Staddon Grits contain Meadfoot fossils. I also emphasize the fact that the Meadfoot Beds include a number of horizons. The truth is that an immense amount of work remains to be done on the zoning of the Devonian, both in North and South Devon and in Cornwall, and, if Dr. Asselberghs' contribution induces some of our local workers to take this up, it

will have done the cause of Devonian geology in this country an inestimable service.

JOHN W. EVANS.

IMPERIAL COLLEGE, SOUTH KENSINGTON.

April 14, 1921.

OBITUARY.

Arthur John Charles Molyneux, F.G.S., F.R.G.S.

MR. A. J. C. MOLYNEUX died suddenly of heart failure at Bulawayo on 28th December in his 55th year. Molyneux came to Rhodesia in the early days, being a member of the Victoria Column under Major Alan Wilson that occupied Matabeleland in 1893. After the settlement of the country he devoted himself to prospecting and mining, making many long expeditions into the outlying districts in which he discovered some of the coalfields of the Territory. In particular he made several traverses across the then little known mid-Zambesi valley from the high veld of South Rhodesia to that of Northern Rhodesia or in the opposite direction, mapping the country, taking precise geological notes, and carefully labelling his specimens. His maps of many of these tracts are still the most reliable and intelligible, since they were made by a man with an eye for country.

He was always intensely keen on the purely scientific side of his work. His spirit may be gauged by the fact that on one trip, when an expected supply of water failed him and it became necessary to make forced marches to save life, he threw away most of his kit, but kept some fossils he had found. These were the ones that first proved the Karroo age of the Coal-measures in the mid-Zambesi basin. He was the first to give an adequate explanation of the wonderful gorge at the Victoria Falls.

Molyneux was earnest in his desire for the diffusion of natural knowledge. He called the inaugural meeting and was first secretary of the Rhodesia Scientific Association. He was also a member of the committee and one of the first trustees of the Rhodesia Museum, established at Bulawayo in 1901. He joined the Geological Survey of Southern Rhodesia in 1917, wishing to place his knowledge of the outlying districts at the disposal of the country, and hoping thereby to work out his early observations. Circumstances, however, demanded his services in other districts, on the geology of which he published a paper and two reports.

For some years his health had not been very good, largely owing to the bad conditions experienced on his earlier travels. After joining the Geological Survey an improvement took place, but at the beginning of 1920 his heart began to give trouble, necessitating residence at sea-level for two periods. He did not long survive his second return to high altitudes.

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JUNE, 1921.

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THE
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Founders of Seismology.—II. Robert Mallet.

By CHARLES DAVISON, Sc.D.

WHILE Michell's interest in geology lasted until at least 1788, he made no further known contribution to the study of earthquakes. He must have been aware of the disastrous Calabrian earthquakes of 1783, but he would no doubt regard them as timely illustrations of his theory. The eighty years which followed 1760 were, indeed, somewhat barren as regards the progress of seismology. Among the more important contributions during this period were Dolomieu's report on the Calabrian earthquakes of 1783, Darwin's memoir on the connexion of certain volcanic phenomena in South America (1838), and the well-known chapters in Lyell's *Principles of Geology* (1830).

About the year 1840 a new period began, a period of rapid progress, during the first forty years of which the outstanding figures were those of Alexis Perrey in France and Robert Mallet in England. A brief reference should, however, be made to the work of David Milne (afterwards Milne Home) on the earthquakes of Great Britain, and especially on the remarkable series of Comrie earthquakes, which began in October, 1839, and lasted for the next six years.¹

The work of Alexis Perrey was almost concurrent with that of Mallet, Perrey's lasting from 1841 to 1875, and Mallet's from 1845 to 1878. Perrey was professor of mathematics at Dijon. Except for his seismic bibliography (1855-65) and his papers on the relation between the frequency of earthquakes and the age of the moon (1853, 1861, and 1875), he devoted himself to the heavy and uninspiring task of cataloguing earthquakes. His catalogues were of two kinds, chronological and geographical. The former consist of lists of earthquakes in all parts of the world for each year from 1843 to 1871. The regional catalogues, seventeen in number, cover the whole of Europe, with the exception of Russia, Scandinavia, Denmark, and Germany outside the basin of the

¹ *Edin. New Phil. Journ.*, vol. xxxi, 1841, pp. 92-122, 259-309; vol. xxxii, 1842, pp. 106-27, 362-78; vol. xxxiii, 1842, pp. 372-88; vol. xxxiv, 1843, pp. 85-107; vol. xxxv, 1843, pp. 137-60; vol. xxxvi, 1844, pp. 72-86, 362-77.

Rhine. Of the other continents, only special regions are considered—in Asia, the Philippine Islands, Japan, and the Kurile Islands and Kamschatka; in Africa, Algeria and the north of the continent; in America, the Antilles, Chile, Peru, and the Aleutian Islands, Alaska, etc. Regarding the interior of the earth as fluid, it was only natural that Perrey should investigate a lunar periodicity¹ in the occurrence of earthquakes, but his three laws of greater frequency at syzygies than at quadratures, at perigee than at apogee, and, for any place, when the moon crosses the meridian, can hardly be regarded as possessing a firm foundation. His chief claim to our gratitude rests on his extensive catalogues. Our knowledge of the history of nearly every seismic region of the globe depends at one point or another on the untiring labours of Alexis Perrey.

In other respects the ground was unoccupied. Our knowledge of individual earthquakes was gradually increasing, the facts of earthquake phenomena were becoming known, but, as yet, there was no science of seismology. The next step was made, not by a trained student, but by a busy practical engineer; and when we think of the work which Mallet accomplished for seismology we should also remember that it was done, for the most part alone and unaided, in the midst of great engineering enterprises.

Robert Mallet was born at Dublin on June 3, 1810, his father, John Mallet, being the proprietor of a factory in which sanitary fittings and small fire-engines were made. At the age of 16 Mallet entered Trinity College, Dublin, taking the degree of B.A. after a four years' course. In the following year (1831) he married and was taken into partnership in his father's factory. This he soon converted into engineering works with a considerable foundry, and before many years had passed all the engineering work of any consequence in Ireland was carried out by the firm. Mallet's first great feat was to raise the roof of St. George's Church, Dublin, a mass 133 tons in weight, and covering a large area. This was followed by the building of several bridges over the Shannon, and the invention and construction of hydraulic rams and of ventilating and heating apparatus for public buildings. His buckled plates, which he began to make in 1840, form one of the best floors ever designed, combining the maximum of strength with the minimum of depth and weight. They are to be found on the Westminster and other London bridges. In 1845-6 he was erecting a railway station while he was working at his first important paper on the dynamics of earthquakes. In 1849-55 he built various station roofs, and the Fastnet Rock lighthouse, and was designing heavy guns and large mortars, the latter capable of throwing 36 inch shells. At the same time he

¹ It is interesting to notice that the possibility of a lunar periodicity occurred to Darwin in 1840. Writing to D. Milne, he remarks, "On the hypothesis of the crust of the earth resting on fluid matter, would the influence of the moon (as indexed by the tides) affect the periods of the shocks, when the force which causes them is just balanced by the resistance of the solid crust?" (*More Letters of Charles Darwin*, vol. ii, 1903, p. 115).

was writing his British Association reports on the facts of earthquake phenomena, determining the velocity of earth-waves in sand and solid rock, and compiling his catalogue of recorded earthquakes. In 1859 he wrote a valuable paper on the coefficients of elasticity and rupture in wrought iron, and at about the same time worked out the results of his investigation of the Neapolitan earthquake of 1857, and made further experiments on the velocity of earth-waves at Holyhead.

In 1861, engineering work becoming scarce in Ireland, Mallet moved to London, where he set up as a consulting engineer and edited the *Practical Mechanic's Journal*. After an active and healthy life his eyes began to fail during the winter of 1871-2, and he was practically, though not quite, blind during the last seven years of his life. He died on November 5, 1881.

"In scientific thought, Robert Mallet was remarkable for the originality of his ideas, and for the broad grasp he took of every subject that engaged his attention; in private and social life he was beloved for the kindness, geniality and humour of his disposition, for his readiness in conversation and uniform good temper."¹

Until he was about 35 years old, Mallet, like Michell, had apparently given no thought to earthquakes. His attention was drawn to them, not by a great disaster, but almost by accident. He had noticed in Lyell's *Principles* the well-known diagram of a pair of pillars, the upper parts of which had been twisted, without being overthrown, by one of the Calabrian earthquakes. He saw at once the flaw in the usual statement that, under each pillar, there must have existed an independent vorticose movement. His practical training suggested a simple mechanical explanation. If the centre of adherence of the base of the twisted portion were to lie outside the vertical plane containing its centre of gravity and the direction of the motion, the result might be the observed rotation.² The problem is one of minor importance. Its interest lies chiefly in the fact that its solution led Mallet to the views on the nature of earthquake-motion which he described in his memoir on the dynamics of earthquakes.³

In this memoir, in addition to the discussion of the problem referred to, Mallet considers the nature of the earthquake-motion in the earth's crust, the nature and origin of seismic sea-waves and of earthquake sounds, the need and use of observations on the

¹ *Roy. Soc. Proc.*, vol. xxxiii, 1882, pp. xx. For the above biographical details I am chiefly indebted to notices in *Engineering*, vol. lii, 1881, pp. 352-3, 371-2, 389-90; and *Min. of Proc. of Inst. of Civ. Eng.*, vol. lxxviii, 1882, pp. 297-304.

² Other, and perhaps more probable, explanations of the movement are given in *Trans. Seis. Soc. Japan*, vol. i, pt. ii, 1880, pp. 31-5, and *GEOL. MAG.*, 1882, p. 264.

³ "On the Dynamics of Earthquakes; being an attempt to reduce their observed phenomena to the known laws of wave motion in solids and fluids" (read February 9, 1846): *Trans. Irish Acad.*, vol. xxi, 1848, pp. 51-105.

velocity of earth-waves, and the advantage of founding earthquake observatories in various parts of the world. There is perhaps little that is really novel in the whole memoir, little, if anything, that the present-day student of seismology would have occasion to consult, and his account of Michell's work is strangely inaccurate and incomplete. Its chief merit is that it does form an attempt to explain the more important phenomena of earthquakes by the light of one guiding principle, and thus, as he says, to bring them within the range of exact science. As W. Hopkins wrote in the following year, he treated the subject "in a more determinate manner and in more detail than any preceding writer".

The principle referred to is that an earthquake is "the transit of a wave of elastic compression in any direction, from vertically upwards to horizontally, in any azimuth, through the surface and crust of the earth, from any centre of impulse, or from more than one, and which may be attended with tidal and sound waves dependent upon the former, and upon circumstances of position as to sea and land".¹ At the same time, he realized that the waves of vibration may "become complicated by movements of permanent elevation or depression in the land . . . the effects of which it may often be difficult or impossible subsequently to separate."

Mallet gives a very full description of the sea-waves which accompany earthquakes. Although he does not follow Michell in separating the visible waves from the waves of vibration on land, he distinguishes two kinds of sea-waves—the forced sea-wave, as he calls it, and the great sea-wave. His explanations of the origin of both are partially incorrect. The forced sea-wave, which accompanies the earth-waves and is "carried upon its back, as it were", is merely the wave of compressional vibrations in water. If the great sea-wave, which sweeps in some time later, were initially raised by the earth-wave, there would be a great sea-wave with every strong submarine earthquake. He does, however, notice that the sea-wave may become "complicated by movements of permanent elevation or depression in the land", and to this extent his explanation is no doubt correct.

Great stress is laid on the importance of determining the velocity of the earth-wave, not so much for the interest of the question in itself, as on account of its geological applications. Mallet was aware that the velocity in any rock must depend on the elastic constants of the rock. If we were to measure these constants for all the different rocks, the knowledge of the velocity in a given submarine earthquake, he suggested, would enable us to predict

¹ Many earlier writers had regarded earthquakes as due to the passage of waves of vibration, e.g. J. Michell in 1760, Thomas Young in 1807 (*Lectures on Natural Philosophy*, vol. i, p. 717), and D. Milne in 1841 (*Edin. New Phil. Journ.*, vol. xxxi, pp. 262, 275-7). In his report on the theories of elevation and earthquakes (*Rep. Brit. Assoc.*, 1847, pp. 33-92), W. Hopkins, treating the theory as obvious or well known, gives an account of wave-motion in solids and liquids that may still be read with advantage.

the nature of the underlying rock-formations—an anticipation which has not, I am afraid, so far been fulfilled.

In his early views on the origin of earthquakes Mallet was in advance of his time. He connects earthquakes with “local elevations of portions of the earth’s crust, often attended with dislocation and fracture of the crust, and sometimes attended with the actual outpouring of liquid matter from beneath.” He imagines an earthquake to be produced “either by the sudden flexure and constraint of the elastic materials forming a portion of the earth’s crust, or by the sudden relief of this constraint by withdrawal of the force, or by their giving way, and becoming fractured”. Where should we look for such sudden changes? Not in volcanic countries, he thinks, but rather in that broad sub-oceanic belt within which the deposits of the land are accumulated and from which they may afterwards be swept away by tidal currents. “Such a condition of the sea-bottom would seem to be the most likely state of things to give rise to frequent and sudden local elevations or even submarine eruptions of molten matter.” And he notices that, while earthquakes are frequent in volcanic countries, they are never of the greatest violence. On the other hand, “the centre of disturbance of almost all the greater earthquakes appears to be beneath the sea, and at considerable distances from active volcanoes,” while “the circumstances of the great sea wave seem to indicate that the centre of disturbance is seldom, if ever, *very* distant from the land”.

I have given a somewhat full account of this important memoir, for whatever its imperfections may be it must, I think, be regarded as the chief foundation-stone of seismology as a science. Fortunately Mallet did not rest content with this, practically his first, contribution. He became afterwards widely known to the scientific public by his four reports to the British Association on the facts of earthquake-phenomena, their publication covering most of the years from 1850 to 1858. His crowning work on the Neapolitan earthquake of 1857 was published in 1862. With this report and with his memoir on the velocity of earth-waves at Holyhead, his career as a seismologist practically ended, for his study on volcanic energy lies outside our range, and his later papers, owing to his practical blindness, were of minor value. After his first memoir Mallet’s work may thus be considered under the following headings: (i) experiments on the velocity of earth-waves; (ii) the preparation and discussion of the catalogue of recorded earthquakes; (iii) the development of methods of investigating earthquakes; and (iv) their application to the study of the Neapolitan earthquake.

Velocity of Earth-waves.—As already remarked, Mallet attached great importance to accurate determinations of the velocity of earth-waves. His first experiments were made in two widely differing materials—the wet sand of Killiney Bay, on the coast of Co. Dublin, and the granite of the neighbouring Dalkey Island. In Killiney Bay charges of 25 lb. of gunpowder were exploded in

the sand, and the passage of the waves at a distance of half a mile was detected by the tremors on the surface of a mercury bath. In Dalkey Island the ranges were of less than half this length (1021–1155 feet), the granite in one set being of a more fissured or shattered character than that in the other. The mean of eight measurements in sand, six in the fissured granite and three in the other, gave the following velocities, after all corrections were applied:—

Sand	825 feet per second.
Discontinuous granite	1,206 " " "
More solid granite	1,665 " " "

The second series of measurements were made at Holyhead from 1856 to 1861, large masses of rock being dislodged from the Government quarries by the explosion of from one to five or more tons of gunpowder in mines. The ranges (six in number) varied from slightly less than a mile to about a mile and a quarter, crossing different lengths of quartz rock, slates, and schists. The velocities varied from 954 to 1,289 feet per second, the average of all six measurements being 1,089 feet per second.¹

Catalogue of Recorded Earthquakes.—In the compilation of his earthquake catalogue, as well as in the experiments described above, Mallet was assisted by his eldest son, the late J. W. Mallet. The catalogue forms his third report on earthquake-phenomena, and occupies nearly six hundred pages in the reports of the British Association. The discussion of the catalogue and the description of the seismic map of the world are contained in the fourth report.² Though based on several earlier catalogues—especially those of Von Hoff, Cotte, Hoffman, Merian, and Perrey—Mallet regarded his catalogue as probably the first attempt to include all recorded earthquakes. The labour involved in its preparation must have been immense. From scattered sources—books of travel, British, French, and German newspapers and scientific journals—the number of entries obtained amounted to about one-half the total number. The details relating to each earthquake are given in tabular form under the six headings: time of occurrence, area chiefly affected, the direction, duration, and number of the shocks, great sea-waves, etc., meteorological and secondary phenomena, and the authorities for the records. The first entry is under the date 1606 B.C., and Mallet originally proposed that the catalogue should end with the year 1850. It was found, however, that the completeness of Perrey's annual catalogues rendered its extension beyond the year 1842 unnecessary, but the earthquakes of the eight omitted years are included in the discussion of the fourth report. The total number

¹ *Rep. Brit. Assoc.*, 1851, pp. 272–317; *Phil. Trans.*, 1861, pp. 655–79; 1862, pp. 663–76. The above velocities are given to the nearest foot per second. Mallet expresses them to three places of decimals. Such detail, however, is meaningless, for an error of one-hundredth of a second in the time of transit at Killiney Bay involves an error of more than 2 feet per second in the velocity.

² *Rep. Brit. Assoc.*, 1852, pp. 1–176; 1853, pp. 118–212; 1854, pp. 1–326; 1858, pp. 1–136.

of earthquakes recorded is stated by Mallet to be 6831, of which 216 were "great" earthquakes, or strong enough to reduce whole towns to ruins. Judging from the last 150 years, during which the record of such disasters may be supposed complete, Mallet estimates that a great earthquake occurs on an average once every eight months. The rapid expansion in the number of entries, especially during the last three centuries, is no proof, in Mallet's opinion, of any actual increase in earthquake-frequency. He regards it as, in fact, "a record of the advance of human enterprise, travel, and observation," the evidence tending rather to the conclusion that "during all historic time the amount of seismic energy over the observed portions of our globe must have been nearly constant." At the same time, there is clear evidence of irregular and paroxysmal outbursts of energy in reference to shorter periods. The frequency curves for the last three centuries and a half (1500-1850) show, indeed, that while the least interval of repose may be a year or two, the average interval is from five to ten years; that the shorter intervals are usually connected with periods of diminished earthquake frequency; that the alternations of paroxysm and repose appear to follow no discernible law; except that two marked periods of extreme paroxysm occur in each century, the greater about the middle and the less not far from the end.

Still more important are Mallet's conclusions on the distribution of earthquakes in space. Previous seismic maps of the world, such as those in the physical atlases of Berghaus and Johnston, were based on imperfect catalogues. In neither, as he notices, is there any attempt made to depict by various tints the greater or less frequency and violence of earthquakes in different areas. Mallet's materials were much fuller, though still far from complete. The original map, on Mercator's projection, is 75 inches long and 48 inches wide (reduced in the report to about one-third linear dimensions). He divided earthquakes into three classes—great, mean, and minor. If their disturbed areas were unknown, he assumed that their radii were 540, 180, and 60 geographical miles, and their areas were coloured by three tints, the intensities of which were as the numbers 9, 3, and 1. Thus, the most deeply shaded areas on the map represent those in which earthquakes are most frequent and violent.

While its defects are obvious, Mallet's map remained for nearly half a century our best representation of the distribution of earthquakes over the globe. The more important results which he deduced from it are the following: as the distribution of earthquakes is paroxysmal in time, so also it is local in space; the normal type of distribution is in bands of variable and great width (from five to fifteen degrees); these bands very generally follow the lines of elevation which divide the great oceanic or terr-oceanic basins of the earth's surface; in so far as these are frequently the lines of mountain-chains, and these latter those of volcanic vents, so the seismic bands are found to follow them likewise; the regions of

least or no disturbance are the central areas of great oceanic or terr-oceanic basins and the greater islands existing in shallow seas. The modern and more accurate method of mapping by epicentres, rather than by disturbed areas, has led to greater detail in our knowledge, but the main laws of seismic distribution* are those which Mallet has so clearly established.

Methods of Investigation.—Though they are not explicitly stated, there can be little doubt, I think, that the methods of investigation which Mallet afterwards developed, were partly present in his mind when he wrote his early papers. Even in the first edition (1849) of the *Admiralty Manual of Scientific Inquiry*, to which, on Darwin's recommendation, he was invited to contribute, there is no direct account of them in the section on the observation of earthquake phenomena. They are described for the first time, and very fully described, in his report on the Neapolitan earthquake, and it is some indication of the importance which he attached to them that the main title which he gave to these two large volumes is "The First Principles of Observational Seismology".

The fundamental object of Mallet's inquiry was to ascertain the surface-position and depth of the seismic focus. The methods which he proposed for this purpose are well known. By observations on the direction of fissures in large and uniform buildings, of the fall of columns, and of the projection of detached masses of masonry, he sought to determine the azimuth or horizontal direction of the shock, and such directions at two or more places would suffice to determine the position of the point vertically above the seismic focus, which we now know as the epicentre. Once this point is determined, a single observation of the angle of emergence, as given by the inclination of fractures in walls, would lead to the depth of, at any rate, one point within the focus.

Various writers before Mallet had suggested the use of observations on the direction of the shock. The earliest case known to me, which I have already quoted (p. 105), is that of J. Michell, in 1760. D. Milne used the method in 1841 to determine the epicentre of the Comrie earthquakes, which were at that time frequent, the directions at different places being obtained chiefly from the records of inverted pendulums. He also made the valuable suggestion that "if instruments could be invented which at different places would indicate, not merely the relative intensity of the shocks, but the direction in which they acted on bodies, means would be obtained of determining the point in the earth's interior from which the shocks originated"¹—a method which, forty years later, occurred to J. Milne, and was used by him, and afterwards by Omori and Hirata, to determine the depth of the seismic foci of some Japanese earthquakes. Lastly, W. Hopkins, in giving (1847) the same method for locating the epicentre, adds the important remark that the direction observed should be that at

¹ *Rep. Brit. Assoc.*, 1841, p. 48; 1842, pp. 96-7; 1843, p. 121; *Edin. New Phil. Journ.*, vol. xxxi, 1841, pp. 276-7.

the first instant of the motion, for, afterwards, the later vibrations of the condensational wave and the earlier vibrations of the distortional wave may coalesce—a precaution which lies at the root of Galitzin's method.¹ It is one thing, however, to suggest a method, and a very different matter to apply it; and few, I think, will be found to deny that, if any name is to be associated with these methods, it should be that of Robert Mallet.

Study of the Neapolitan Earthquake of 1857.—Owing to his long residence in Ireland—a typical aseismic country—Mallet had no direct acquaintance with earthquakes until 1852. On November 9 of that year he was awakened by a strong shock, one that is perhaps unique among British earthquakes in having affected all four portions of the United Kingdom. It failed, however, to give him the materials that he required, and five years more had to pass before they were provided by the Neapolitan earthquake of December 16, 1857. Leaving Naples on February 10, he spent several weeks visiting the ruined towns and villages of the meizoseismal area, heedless of the many discomforts of a camp life during the wet and cold of winter, convinced that in fractured walls and overthrown pillars he had “the most precious data for determining the velocities and directions of the shocks that produced them”, inspired by the thought that for the first time the depth of the seismic focus was being “measured in miles and yards with the certainty that belongs to an ordinary geodetic operation”. Sixty years have passed since then; the certainty of 1858 may have given way to doubt; yet, as one reads the account of his work at Polla and Vietri di Potenza, when he realized that at last he had found the point vertically above the origin of the shock and could state, as a first approximation, that the depth of the focus was 5·64 geographical miles, one cannot but sympathize with his confidence that he was showing the way to a true intelligence of “the viewless and unmeasured miles of matter beneath our feet”.

Mallet's report on the Neapolitan earthquake is the first of a long series of monographs on shocks of special strength or interest, and for forty years, until the Assam earthquakes of 1897, it remained without a rival. His map of the earthquake marks an epoch in seismology. For the first time isoseismal lines were drawn on such a map. There are four of these. The first surrounds the meizoseismal area, within which the towns were for the most part prostrated; the second includes places in which large parts were thrown down and persons were killed; the third those in which slight damage to buildings occurred without any loss of life; while the fourth bounds the area within which the shock was perceived by the unaided senses.

On this map Mallet also depicted the lines of wave-path at different places, taking the most probable mean direction when more than one was measured. The majority of the observations he found to

¹ *Rep. Brit. Assoc.*, 1847, pp. 82-3.

pass within a circle, $2\frac{1}{2}$ geographical miles in radius, with its centre close to the village of Caggiano. Of twenty-six separate wave-paths, twenty-three start from the vertical line through this centre at depths of less than $7\frac{1}{8}$ geographical miles. The mean depth of the focus he estimated at $5\frac{3}{4}$ geographical miles, and the probable vertical dimension of the focal cavity at about 3 geographical miles. Some of the azimuths, however, pass outside the Caggiano circle. From their various points of intersection Mallet concluded that the focal cavity was a curved fissure 9 geographical miles in horizontal length. The mean velocity of the earth-waves he found to be 788 feet per second. The amplitude and maximum velocity of the vibrations naturally varied greatly. At Polla, which is close to the epicentre, he estimated the amplitude at $2\frac{1}{2}$ inches, and the maximum velocity at 13 feet per second.¹

Conclusion.—To sum up Mallet's contributions to seismology is not an easy task. One of the most important is also the most intangible—his influence on the different points of view from which earthquakes were regarded, say in 1845 and after the lapse of twenty years. Fifteen years after his death and nearly forty years after the Neapolitan earthquake, I was struck by the fact that of more than two thousand observers of the Hereford earthquake of 1896, one in every five gave unasked the direction of the shock. In the large towns the proportion rose to one in every three.

"It is given to no man," said Mallet, "so to interpret nature that his enunciation of her secrets shall remain for ever unmodified by the labours of his successors." Mallet's work was unfortunately no exception to this rule. Some of it may now be obsolete, but much of it remains. Several of the terms in daily use—seismology, seismic focus, angle of emergence, isoseismal line, and meizoseismal area—are due to him. The position of the epicentre may still be determined by observations on the direction of the shock, especially by the mean of a large number of observations. As regards the depth of the focus, the results derived from such observations are much less certain. All that can be said is that they perhaps indicate the order of magnitude of the true depth. His experiments on the velocity of earth-waves are interesting, though their bearing on the actual problem is somewhat remote. But, by his perception of the nature of earthquake-motion, by the construction of isoseismal lines, by the compilation of his great catalogue, by his statement of some of the laws which govern the distribution of earthquakes in time and space, and, above all, by his investigation—the first rational investigation—of a great earthquake, Mallet has placed the science of seismology under a debt, which those who have followed in his steps would be the last to underestimate.

¹ A more detailed account of Mallet's investigation is given in my *Study of British Earthquakes* (Contemporary Science Series), pp. 7-44.

ORIGINAL ARTICLES.

Precambrian Para-Gneisses of Southern Eyre Peninsula, South Australia.

By C. E. TILLEY, Emmanuel College, Cambridge.

(PLATE III.)

CONTENTS.

1. Introduction.
2. The Sleaford Bay Section.
3. The Garnet Gneisses.
 - (a) General Description.
 - (b) Petrography.
4. Origin of the Garnet Gneisses.
5. Summary.

1. INTRODUCTION.

IN an earlier paper¹ a description of certain dolomites and calc-magnesian silicate rocks of the oldest group recognized in southern Eyre Peninsula—the Hutchison series—has been given.

Intimately associated and interbanded with these dolomites occur a group of garnet gneisses along the shores of Sleaford Bay. A portion of the section exposed in this place was figured in the paper referred to.

The present notes are devoted to a description of these garnetiferous gneisses exposed at Sleaford Bay, together with a short account of some similar gneisses developed in the Hutchison area to the north.

2. THE SLEAFORD BAY SECTION.

To the section already given in the previous communication a second is now added (Fig. 1 of the present paper). This section represents a continuation of the rocks exposed in an easterly

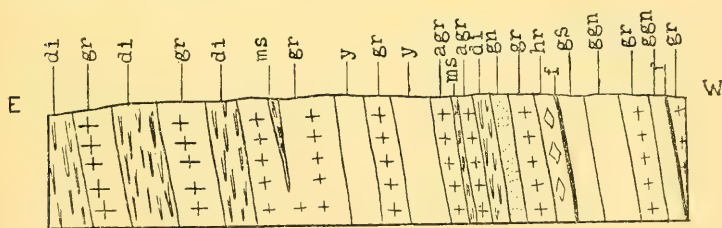


FIG. 1.—Section along the shore at Sleaford Bay.

gr = granite, agr = aplitic gneiss, di = diopside rock, ms = mica schist, f = ironstone band, ggn = garnet graphite gneiss, hr = hornblende schist, gn = garnet gneiss, y = ? kaolinized schists with pegmatite veins.

direction. A number of beds forming the eastern extremity of the first section are again inserted in the accompanying diagram. The total length of section now revealed is approximately half a mile.

¹ C. E. Tilley, *GEOL. MAG.*, Vol. LVII, 1920, pp. 449–62, 492–500.

The members of the Hutchison series have been penetrated by sills of granite and pegmatite, and by veins of pegmatite and quartz, and composite rocks have in some cases thus arisen, consisting of bands of sediment alternating with igneous material.

3. THE GARNET GNEISSES.

(a) *General Description.*

The typical exposures of the garnet gneisses occur in the section immediately to the east of the massive beds of diopside-rock, which forms here a prominent headland on the coast. The gneisses are interbanded with the calc-magnesian silicate rocks (diopside-microcline-scapolite type) already referred to. The rapid change in composition of the rocks across the strike in this locality is remarkable. The garnet gneisses are conformably bedded with the calc-silicate sediments, striking north and dipping at a high angle—vertical to 80 degrees to the west. The most marked feature of the garnet gneisses as seen in the field is the parallel banded structure, which is essentially a structure arising from initial differences of composition in the original sediments. In certain cases banding has arisen due to the lit-par-lit intrusion of pegmatitic veinlets in the series, but a parallel structure arising in this way can be readily distinguished from the parallel banding due to original heterogeneity in the sediments. Additional garnet gneisses which enter for description here are developed to the east of the graphite gneisses (cf. section Fig. 1).

Here the banding is still evident, but garnet does not form such a prominent constituent. These are associated on the east with gneissic aplites, which in the field resemble these rocks in some particulars, but a study of thin sections reveals an essential distinction.

A bed of garnet gneiss with a well-developed parallel banding is present on the shore to the east of the sill of hornblende granite which borders the forsterite marble. It is separated from the granite sill by a thin bed of graphite schist.

(b) *Petrography of the Garnet Gneisses.*

(i) *Type a.*—The three types of garnet gneisses will be distinguished in this description by the prefixes α , β , γ , and this order is one of exposure from west to east. Their positions can be readily made out by reference to the sections. Type α is a banded rock of greyish colour and, often with rusty weathered faces. In hand-specimens quartz, an unstriated feldspar, garnet, and biotite can be detected, and also sparing flakes of graphite.

The parallel banding can be seen even in small fragments, as the width of the individual bands seldom exceeds $\frac{1}{8}$ in. The rose-pink garnets often show well-developed crystal outline (dodecahedra), and on weathered faces give rise to brown limonite. The rusty

weathering sometimes developed in these rocks is due to this degradation of garnet. The bands of quartz and felspar with garnet are separated by thin layers of biotite. The garnets reach $\frac{1}{4}$ in. in diameter, but average under $\frac{1}{8}$ in. Lenses of pegmatite with their long axes parallel to the surface of banding are occasionally present, and are readily picked out by their coarse texture.

In thin section the following minerals are seen to be present: Quartz, orthoclase, biotite, garnet, ilmenite (with leucoxene), plagioclase, graphite, and zircon.

Within the limits of the field of view of the 1 in. objective, the parallel banding of this rock is a marked feature. The mineralogical composition of the bands separates them into quartzose and feldspathic layers.

Biotite occurs in elongated flakes, showing parallel orientation. The pleochroism is strong, and the scheme is—

Z = Y, red brown. X, pale straw yellow.

Faint pleochroic haloes surround small inclusions of zircon. The principal felspar is orthoclase, often intergrown with quartz. It is very characteristically a fibrous type, and is the dominant feature of the orthoclase felspar of all the garnet gneisses of this area.

The fibrous appearance is due to the presence of minute grains arranged parallel to the face (100), and the fibrous character disappears in many sections showing straight extinction. These features indicate the presence of an intergrowth which is probably perthitic, but the minuteness of the grains prevents the determination of other properties. In addition, in some of the orthoclase grains there are large spindle-shaped grains of a colourless mineral of higher relief and birefringence. They are oriented slightly obliquely to the perthitic type. In some cases these are certainly quartz, but in others represent an acid plagioclase. The quartz grains are characteristically elongated parallel to the banding surface, and may show rows of fluid pores at right angles to their elongation. In some sections the average elongation ratio reaches a value as high as 3 : 1.

Plagioclase is not abundant. It shows albite and pericline lamellation. The refractive index is about the same as quartz, but lower than the highest of quartz, and the sign of the birefringence is negative. The properties are those of an oligoclase-andesine. Myrmekitic intergrowths of plagioclase and quartz occur at the junction of plagioclase and orthoclase and often extend in a bay into the potash felspar.

Garnet is present in colourless porphyroblasts of rounded outline, with the typical quartz enclosures. It is usually quite isotropic, but an occasional grain shows anomalous birefringence, in one case with twinning lamellæ. The grains reach 3 mm. in size, but are usually smaller. The garnet is an almandine type, as might be expected in rocks of this class. This is confirmed by the characteristic

limonitic weathering product, and its fusion before the blowpipe to a black magnetic mass.

The colour of some of these garnets as seen in hand-specimens is often the characteristic purplish red of almandine.

Biotite and quartz are often wrapped around the periphery of these grains.

Graphite is invariably present in these rocks, and in some sections may rise to an important constituent. The orientation of the graphite flakes is like that of biotite, parallel to the banding, and in sections cut perpendicular to the foliation the flakes appear as elongated rods. In reflected light the flakes appear with a steel-grey lustre, like that of magnetite. The rod-like sections, however, have the characteristic frayed and serrated edges and a striated appearance on the ground surface, these features arising as a result of the softness of the mineral during grinding.

In these rocks these features, together with the rod-like sections, afford a ready means of distinction from magnetite. The graphite is usually associated with biotite, and is often enclosed by that mineral.

The order of abundance of the chief minerals in the rock is quartz, orthoclase, biotite, garnet, and plagioclase.

(ii) *Type β*.—The garnet gneisses described under this heading are interbanded with metamorphosed impure dolomites, now represented by rocks in which diopside is an important constituent. These gneisses are very similar to type *a* already described, but the banding and texture are here of a coarser nature. Rose-pink to purplish-red garnets are abundant often with good crystal outline, and average size of $\frac{1}{4}$ in. Dark mica is more abundant, and the general colour of fractured surfaces is dark grey. Steel-grey flakes of graphite are readily made out with a low-power lens. Weathered surfaces may show a prominent augen structure, the augen being of garnet, quartz, and felspar. These gneisses have in places been intruded by pegmatite veins, and composite types may thus be developed, in which part of the felspathic constituent is original and part introduced.

Under the microscope the minerals seen to be present are quartz, orthoclase, garnet, biotite, plagioclase, graphite, leucoxene, sphene, zircon, and a little muscovite and magnetite. The features of these rocks are so closely allied to those described for type *a*, that a detailed description is unnecessary. The potassic felspar is the typical fibrous perthitic variety. Plagioclase is more abundant than in type *a*, but is of the same composition—oligoclase andesine. A number of grains as calcic as andesine were, however, determined.

Almandine garnet occurs in grains of somewhat larger dimensions, and is invariably isotropic. The presence of the spessartite molecule is indicated by the presence of manganese. The remaining constituents of the rock swing round in a bulge when the almandine porphyroblasts are met. The elongated lenses of quartz parallel to

the foliation are a typical feature. Graphite is invariably present in the serrated rod-like sections, the orientation being that of the banding.

A finer grained rock of this type has the appearance in hand-specimens of a garnetiferous quartzite, but banding is still in evidence.

In thin section the rock is seen to be considerably more quartzose than the type already described. Plagioclase is a more important constituent, and the fibrous character of the orthoclase is less marked.

The garnets are characterized by a polygonal outline indicating a good crystal form. The banded character of this rock as seen under the microscope is strongly marked. The plagioclase shows curved albite lamellæ and wavy extinction due to strain, and often contains blebs of orthoclase as inclusions. The composition varies in different grains from oligoclase-andesine to a calcic andesine. In a further variety the minerals sillimanite and green spinel enter as accessory constituents.

The rock is very rich in quartz, and the fibrous perthitic character of the potash felspar, which is the next abundant constituent, is strongly developed.

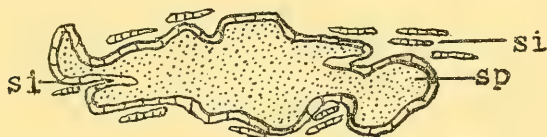


FIG. 2a.— $\times 50$ diam. si = sillimanite, sp = spinel.

Biotite is plentifully distributed with its elongation parallel to the foliation. The pleochroism is—

Z = Y, dark brown. X, light yellow.

The sillimanite is developed in colourless elongated prisms with the prismatic axis parallel to the foliation.

These longitudinal sections show the characteristic cross parting parallel to the base. The elongation is positive. Usually the prisms are arranged in streaks and bands in the orthoclase, but may be associated with the garnet, which is present in irregular isotropic grains.

Very closely associated with the sillimanite occurs a deep-green spinel, which must be regarded as a member of the pleonastehercynite group, and probably nearer hercynite in composition, as the colour is a very deep green.

Some magnetite grains are associated with sillimanite in a similar fashion.

The sillimanite occurring in association with spinel forms a border

to the spinel grain, and the relationship is shown in the accompanying diagram (Fig. 2 (a)).

The sillimanite shell is not optically continuous, nor does the optical orientation bear a constant relation to the external shape of the spinel core.

(iii) *Type γ*.—This type of garnet gneiss outcrops to the east of the graphite gneisses shown in the section.

The rocks are fine-grained and microscopically have the appearance of quartzites. Garnet is present, but not in abundance. On the east they are associated with gneissic aplites, distinguishable by their texture and appearance in thin section. Under the microscope the rock is seen to consist of quartz orthoclase, biotite, garnet sillimanite, and a few grains of magnetite.

Quartz is very abundant in the slides, and has characteristically arranged in rows at right angles to the banding inclusions which appear to be of the nature of fluid pores.

These rows of dots are not only continuous through several contiguous grains of quartz, but also pass through adjacent grains of feldspar. The phenomenon is clearly a result of shearing stress acting on the rock since its recrystallization, and the identical features of the Röhrsdorf granulites of Saxony are here recalled.

The feldspar is the turbid perthitic orthoclase already described. Biotite occurs in elongated flakes parallel to the foliation, and the garnet, usually quite colourless, is often elongated parallel to the foliation, indicating a development under considerable stress.

Embedded in orthoclase, but with a streaky development, occur sillimanite needles, the orientation of the prismatic axes being parallel to the banding.

There is no evidence of granulation along the lines of sillimanite development.

A variety of this type contains in addition a green spinel, and the rock is richer in garnet. Quartz is again the most abundant constituent. The feldspar is the fibrous orthoclase, and plagioclase is rarely observed.

The garnets are characterized by a habit, elongated in the direction of foliation. The elongation ratio of some of the apparently single grains may reach and exceed a value of 4 : 1. The significance of this will be dealt with hereafter, but it is clear that single grains have crystallized originally in a distinct elongated habit.

Hercynite, or a member of the hercynite-pleonaste group of spinels, is present and invariably associated with the garnet. It usually forms a deep-green isotropic core to a garnet grain, or may appear intergrown with this mineral. The depth of colour is not constant, and a gradation to an intense dark-green almost opaque type is observed (Fig. 2 (b)).

In one core of a garnet grain the spinel appears to have undergone alteration to a serpentinous product, in which are set residual grains of the spinel.

The garnet may sometimes contain minute rods of ilmenite (?), and scattered through the rock are opaque leucoxenic grains of the same mineral. Little prisms of sillimanite with their longer axes parallel to the banding are sparingly present in the orthoclase, or in some cases associated with the garnet.

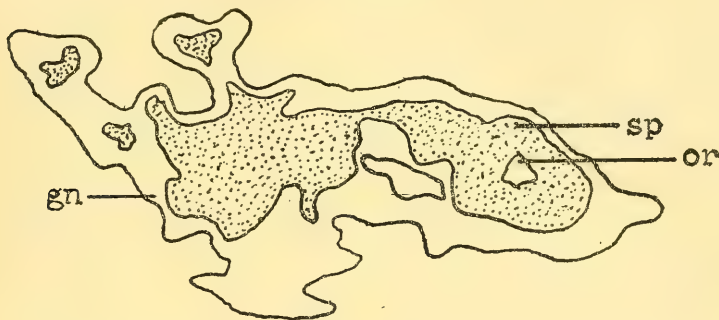


FIG. 2b.— $\times 50$ diam. gn = garnet, sp = spinel, or = orthoclase.

(iv) *Type δ .*—Amongst the complex of metamorphosed sediments present in the Hutchison area, there are certain garnet gneisses, which in their field relations and microscopical character closely resemble the garnet gneisses of Sleaford Bay.

They are typically developed in the Waterfall Creek, and bound the dolomites of this area on the east.

These garnet gneisses are conformably bedded with the dolomites and strike north-east with a vertical inclination.

Those types which are allied to the Sleaford Bay occurrences will be here described.

They are dark-grey rocks with prominent garnets of a brownish-red colour, showing dodecahedral outline, and may be developed up to half an inch in size. Banding is a prominent feature.

Sillimanite may be detected in some specimens, with the aid of a lens, in long fibrous needles.

In places they have been invaded by quartz and pegmatite solutions, giving rise to lenses parallel to the foliation.

A rusty weathering appearance may be given to these rocks by the alteration of garnet to a limonitic product.

Under the microscope the typical sections are seen to consist of orthoclase, quartz, garnet, biotite, sillimanite, plagioclase, ilmenite. Orthoclase is the most abundant constituent. The fibrous character is not in evidence, but perthitic spots are present, characterized by higher refractive index and birefringence—essentially an albitic plagioclase.

The orthoclase shows considerably undulose extinction, and the periphery of the grains is marked by granulation giving the typical mortar structure. Quartz is never in large grains, but forms small individuals in bands separated by felspar.

Garnet may have a quite well-developed crystal outline. These grains reach 3 mm. in diameter. Owing to a prominent development of the dodecahedron the crystals are mainly rhombic and hexagonal in cross section, although elongate types are also occasionally developed. Through the prevalent occurrence of many inclusions of quartz, orthoclase, and biotite, the garnet shows the typical sieve structure. Green spinel may be intergrown with the garnet.

Along cracks biotite is developed (Pl. III, Fig. 1), and in some cases this is replaced by chlorite. This represents a degradation of the original garnet. In the angles of the grains biotite and quartz are often thickly developed, and this type of association is one of genetic significance. It is distinct from the development of biotite along cracks in the garnet, but is related to this change in that it represents a reaction which is a reversible one, the minerals involved being biotite and quartz on the one hand and garnet and orthoclase on the other (cf. equation in a later section).

The biotite is the characteristic red-brown variety, with intense pleochroism.

Sillimanite is an abundant constituent, and may form a zone of slender prisms at the periphery of garnet grains, a relationship in many cases of genetic significance. More characteristically it is present in streaks through the rock parallel to the banding and associated with orthoclase or biotite. The cross parting parallel to the base is a dominant feature.

Plagioclase is present in quite subordinate amount. It shows the albite lamellation, but the twinning lamellæ are usually bent owing to strain. The R.I. is greater than quartz. The majority of grains are positive, but a number show negative birefringence. Extinction angles from the albite lamellæ are quite unreliable owing to the shadowy extinction. The composition of the plagioclase is therefore at least as calcic as andesine.

This rock has suffered crushing, as indicated by the pronounced wavy extinction and granulation of the felspar.

In a varietal type containing a larger percentage of plagioclase the abundant porphyroblasts of garnet are intersected by a set of parallel cracks coincident with the foliation, and not normal thereto, as is usually the case. This structure implies the action of mechanical forces, the direction of the maximum pressure being at right angles to those in operation during the foliation and recrystallization of the rock (Pl. III, Fig. 2).

The fracturing of the garnets has evidently been induced in an epoch subsequent to the recrystallization, and may be connected with the pronounced crushing these rocks have undergone as revealed by the extensive granulation of the felspar.

Interbanded with these rocks occurs a garnet gneiss, showing coarse felspar porphyroblasts as well as garnet.

Under the microscope plagioclase is seen to be the dominant felspar, while orthoclase is the subordinate type.

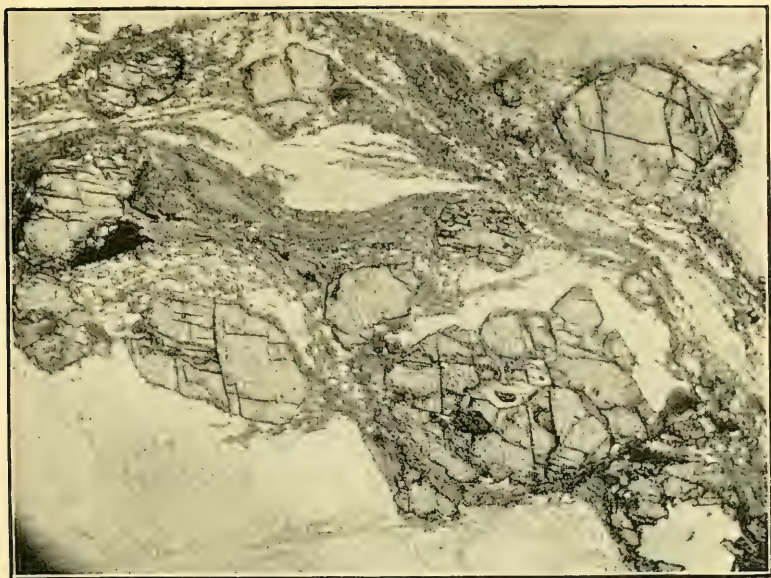


FIG. 2.

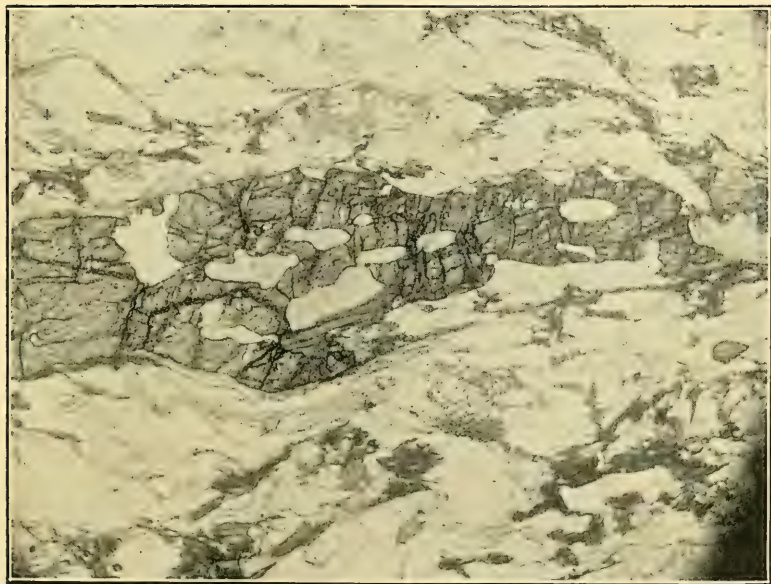


FIG. 1

This plagioclase has the composition of andesine, and around these larger grains flow the finer grained aggregates of quartz, biotite, and orthoclase. The undulose extinction and mortar structure are very marked features. This rock is of a remarkable composition for a sediment, but the field associations point to a sedimentary origin, as does also the abundance of fine-grained quartz.

The plagioclase probably represents recrystallized detrital plagioclase, the original rock being of the nature of an arkose. The garnet represents the by-product of the biotite-quartz interaction in the production of the orthoclase felspar.

(To be continued.)

An Outline of Chinese Geology.¹

By J. S. LEE, M.Sc., Birmingham.

BEFORE we properly discuss the geology of China a few words on the geological work in that country will not be superfluous. Let us first of all ask the Chinese themselves if they, in the course of their intellectual evolution for thousands of years, have contributed anything valuable to our science. The inquiry into this point by the writer has so far been met by a negative answer. True, in ancient Chinese literature one often finds fragmentary suggestions and allegorical statements related to geology. As a typical example we may take the well-known expression "blue seas change into mulberry fields". This sentence is much quoted by popular writers either for depicting the ephemeral state of worldly affairs or for illustrating the slow, mighty change that persistently takes place on the earth. It is in the latter sense that it demands our attention. Again, there are a number of volumes both extremely ancient and comparatively modern treating of the drainage systems of China, and in some cases with rough indication of changes of the sea level. The descriptions of minerals like those in the "Bên-tsao-gang-mong" are certainly a record of incipient development of mineralogical study originated in China and by the Chinese; but as to the purpose, it was anything but geologic.

In recent years the devoted attitude of the Chinese literati to their metaphysical speculation and literatural indulgence has reluctantly but necessarily undergone a fundamental change under the pressing and penetrative influence of modern organized intellectual movements. Among the sciences thus introduced into China geology occupies its rightful place. Institutions for geological study have been established. A Geological Survey with Mr. V. K. Ting as the Director has already commenced its work. Although the *Record*

¹ This paper is an abstract of a Thesis which Mr. Lee submitted for the M.Sc. degree of the University of Birmingham in 1918, dealing with the Geology of China. The author is now Lecturer on Palæontology in the University of Peking, and attached to the Geological Survey of China. He has asked me to see the present paper through the press.—W. S. BOULTON.

of the Work of the Geological Institute is so far the only document of its kind published in Chinese, we have little doubt that there will be a voluminous flow of Chinese geological literature in the near future.

Our present knowledge, then, is largely derived from the scientific writings of the western world. R. Pumpelly, in the years 1862–5, was the first to make a serious attempt to unravel the geological structure and history of Northern China. Three years later F. Richthofen began his life-work. As predecessors or early contemporaries of Richthofen perhaps we should mention A. David, who travelled across the Tsing-ling Range, in Mongolia, Kiang-si, and other provinces; T. W. Kingsmill, who visited many parts of the Yang-tze Valley; A. S. Bickmore, who journeyed from Canton to Hankow. Their labours, however, unlike the case of Richthofen, only resulted in the contribution of a few papers and comparatively brief reports.¹

In the years 1877–80 L. Loczy² attached himself to the Expedition of Szechényi, and worked under difficult conditions in the lower Yang-tze Valley, parts of the Tsing-ling Range, the north part of the Nan-shan Ranges, the mountainous region of western Su-chuan and western Yun-nan. Several years later V. A. Obrutchov,³ a Russian geologist, crossed and re-crossed the Nan-shan Ranges, and penetrated as far south as the northern border of the Great Red Basin of Su-chuan. Observations were also made by the same author in Inner Mongolia. K. Futterer⁴ devoted himself for a time to the study of the geology of Central Asia and China. In journeying from the north-western border of the country to the Yang-tze Valley, Futterer gathered much material that deserves further analysis.

¹ A. David, *Journ. d'un voyage en Mongolie et d'un voyage en Chine dans le Kiang-si*; *Journ. de mon troisième voyage d'exploration dans l'Empire chinois*. T. W. Kingsmill, "Geology of the East Coast of China": *Journ. Geol. Soc. Dublin*; "A Sketch of the Geology of a portion of Quang-tung Province": *Journ. Brit. Roy. Asiat. Soc. N. China Br.*, n.s. II, 1865, pp. 1–38; "Notes of the Geology of China": *Quart. Journ. Geol. Soc.*, vol. xxv, 1869. A. S. Bickmore, "Sketch of a Journey from Canton to Hankow, etc.": *Journ. Brit. Roy. Asiat. Soc. N. China Br.*, n.s. iv, pp. 1–20, 1867; "Remarks on the recent Geol. Changes in China and Japan": *Amer. Journ. Sci. and Arts*, ser. ii, pp. 209–17, 1868.

² L. Loczy, *Die Beschreibung d. geol. Beob. u. d. Result. d. Reise d. Grafen Bela Szechényi in Ostasien*, 1877–80.

³ V. A. Obrutchov, *Central Asia, Northern China, and the Nan-shan* (in Russian); "Geol. Sketch along the route from Fun-chou-fu to Lan-jo": *Izv. I.R.G. Soc.*, vol. xxix, 1893, pp. 391–407; "Kurz geol. Ski. d. Karawanstrasse v. Kjachta b. Kalgan": *Izv. I.R.G. Soc.*, vol. xxix, pp. 347–390; "Sketch of Central Nan-shan Range": *Izv. I.R.G. Soc.*, vol. xxx, 1894, pp. 709–34; "Orogra. u. geol. Umriss d. Central Mongolei, Ordos, Ost Kan-su u. N. Shen-si": *Izv. I.R.G. Soc.*, vol. xxx, 1894, pp. 231–53.

⁴ K. Futterer, "Durch Asien: Die allgemeinen geol. Ergeb. d. neu. Forsch. in Zentral-Asien u. China": *Peter. Mitt.*, 1897, Erg. Nr. 119, pp. 1–60; "Ueber Gestalt u. Gliederung einer Grundlinie in d. Morphologie Ostasiens": *Peter. Mitt.*, vol. xlvii, 1901, pp. 140–2; "Die geol. Bild. Centralasiens u. Chinas": *Verh. Naturw. Ver. Karlsruhe*, vol. xiii, pp. 205–8.

F. Leprince-Ringuet¹ in 1898-9, acting on the instruction of the French Ministry of Foreign Affairs, made observations in the Shan-si coal-field, and dealt to some extent with the general structure of Northern China. The stratigraphical results obtained by Lorenz² from his field-study in Shan-tung and from his palæontological research are distinctly of scientific value. Vogelsang's³ report on his journey in northern Chi-li and western Hu-peh contains useful data for petrographical and tectonic study.

While these writers intermittently pursued their researches, Richthofen was all the time publishing original papers and parts of his epoch-making work *China*. Unfortunately he did not live to complete the latter. A few years before Richthofen's death Dr. Bailey Willis was appointed to take charge of the Carnegie Expedition. After a discussion with Richthofen of a most profitable route for the expedition, Bailey Willis and E. Blackwelder carried out a reconnaissance in western Shan-tung, southern Manchuria, the adjoining districts of Chi-li and Shan-si, central Shan-si, the bordering area between Shen-si, Su-chuan, and Hu-peh, and the Yang-tze Gorges. They obtained much valuable information⁴ within a relatively short period of time. Dr. Willis recognizes several physiographic stages in Northern and Central China from a geo-morphological point of view. The application of this method is especially fascinating for the study of Chinese geology, not because of its novelty to some geologists, but because of the fact that China has been essentially a continental country since the latter part of the Jurassic period; and therefore we are forced to look into the successive stages of erosion instead of merely relying upon the meagre record of deposition. As a summary of the results obtained by the Carnegie Expedition and by the previous workers, Dr. Willis published a comprehensive but somewhat hypothetical account of the *Systematic Geology of China*.

As to the south-western provinces, our geological knowledge is almost exclusively due to the labours of French explorers.⁵ Beginning

¹ Leprince-Ringuet, "Etude géol. sur le nord de la Chine": *Ann. d. min.*, sér. ix, vol. xix, 1901, pp. 346-429.

² Th. Lorenz, "Beitrage z. Geol. u. Palæont. v. Ostasien unter besond. Berück. d. Prov. Shan-tung in China": *Zeits. d. d. Geol. Gesell.*, vol. lviii, pp. 438-97, and vol. lviii, Aufsätze, pp. 53-107.

³ K. Vogelsang, "Reisen in nord. u. mittl. China": *Peter. Mitt.*, vol. xlvii, pp. 241-78, and vol. l, pp. 11-19.

⁴ Bailey Willis, *The Research in China* (1903-4), Carnegie Institution.

⁵ Leclère, *Etude géol. et. minière d. prov. chinoises voisines du Tonkin*. Monod, "Contribution à l'étude géol. d. prov. merid. de la Chine": *Bull. éconm. Indo-Chine*, vol. iv, pp. 619-37; "Annonce l'existence de la huile devonienne, etc.": *C.R. Acad. Sci.*, vol. cxxxii, pp. 270-2. H. Lantenois, "Note sur la géologie et les min. de la région comprise entre Lao-kay et Yunnan-sen": *Ann. d. min.*, sér. x, liv. iii, pp. 300-84, and liv. iv, pp. 385-503, 1907. A. F. Legendre, "Massif Sino-Thibétain, Province d. Setchouen, d. Yunnan et Marches thibétaines"; "de la géologie d. pays Lolo": *Bull. Mus. d'hist. nat. d. Paris*, 1910, No. 1, pp. 59-62. J. Deprat and H. Mansuy, "Etude géol. d. Yunnan oriental": *Mem. d. Service géol. d. l'Indo-Chine*, 1912-13.

with the expedition of the Me-kong, there followed the missions of Leclère and Lantenois. The recent research of Dr. J. Deprat has brought many points of scientific interest to light. His establishment of the Fusulinidæ zones for the marine Carboniferous and Permian is likely to assume universal importance. His report on the geology of eastern Yun-nan is particularly notable in its precision and lucidity.

So much for the history of geology in China. Now we come to the geological history of China. In dealing with such a stupendous subject as this, one may be sure at the very beginning that it is impossible to enter into details in this short paper. Moreover, the fragmentary nature of our present knowledge must naturally necessitate the introduction of risky assumptions and hypotheses in attempting to form a connected view of the successive geological changes that have taken place in the vast area of eastern Asia since Archæan time. Nevertheless, we feel the pressing need of linking up, so to speak, the available authentic information so that some ideas may be obtained as to what has been done in the past and what is to be done in the immediate future. This paper is, therefore, primarily meant to be a synthetic review of the existing literature rather than a summary of critical analyses of the same. Only those points which appear to be of utmost importance are raised and briefly discussed.

THE GENERAL STRUCTURE OF CHINA.

China Proper may be divided, for the convenience of a broad tectonic consideration, into two parts of approximately equal dimension, between which runs the long range of the Tsing-ling from west by north to east by south. The area to the north of this range or Northern China is further divisible into three parts of different structure.

1. In the north-eastern area there occur parallel folds principally running north-east or east-north-east, and occasionally accompanied by secondary undulations with their axes running east to west.¹ The Palæozoic rocks are in many places involved in these folds; while the Jurassic are apparently free from their influence. In the mountains of north-western Chi-li the north-east folds are so remarkably well developed that after a glance at Richthofen's geological map one can hardly fail to appreciate the meaning of his appropriate term the "Grid of Peking".

2. In the north-western area we find a series of high mountains, the Nan-shan Ranges, running from north-west to south-east, and gradually bending in between longitudes 103°-104° E., into arcs with their concave side facing the north, i.e. more or less concentric with the Irkutsk-Amphitheatre of Suess. The tectonic axes of the Nan-shan Ranges generally agree with the mountain trend except for Mesozoic synclines that in some cases obliquely traverse the ranges.

¹ F. N. Drake, "The Coal-field of North-East China": *Trans. Amer. Inst. Min. Eng.*, 1901-2, pp. 492-512.

3. The central area comprises the provinces of Shan-si, Shen-si, and a part of Kan-su, and constitutes a huge barrier which arrests or deflects the waves of folds coming from the north-east and the north-west. The eastern part of the central block, namely, the province of Shan-si, with gently inclined Palæozoic and Triassic (?) strata, is divided up by mighty faults running more or less in parallelism with the Fen-ho valley. Towards the south-western corner of the province of Shan-si, where the Hwang-ho suddenly sweeps round from a north-south course to east-north-east, the faults look as if being progressively compressed till a single line of fracture, the Wei-ho fault, takes their place. The latter extends for a considerable distance along the northern foot of the Tsing-ling Range.

Tectonically related to but physiographically separated from the "table-land of Shan-si" is the province of Shan-tung, which Suess justly discusses as a "shattered horst".

In Southern China, or the area to the south of the Tsing-ling Range, large tectonic units are not so readily recognizable as in the northern part of the country. Nevertheless, we can make use of certain prevailing structural features so as to render an equally broad analysis possible.

1. Let us begin with the mountainous region of western Su-chuan. There highly compressed parallel folds run predominantly from the north to the south. On reaching northern Yun-nan the folds tend to open out, that is to say, they appear to bend slightly round the Tibetan Plateau on the one side and follow the elbow of the Yang-tze on the other.

2. Immediately to the east of the north-south folds of western Su-chuan and to the south of the Tsing-ling Range, a plain known as the Great Red Basin of Su-chuan spreads itself out over a considerable area. The basin is filled up by a formidable sequence of Mesozoic and post-Mesozoic strata folded, in its south-eastern part, into a series of sharp anticlines with their trend varying from north-east to north-north-east.

3. South-Eastern China, or the area to the east of the Yang-tze Gorges and the Kwei-chou Plateau, appears to descend from the highland of South-Western China by a gigantic step either in the form of a flexure or fractures, or probably both. If the line indicating the "Hwa-kiang Flexure" (extending from about long. $106^{\circ} 40'$ E., lat. 25° N. to the north-east) of Leclère¹ be produced to the north-east, it would significantly pass along the eastern edge of the Kwei-chou Plateau, where signs of a powerful dislocation have been witnessed by Wingate,² and would fall in line with the axis of the Hwang-ling Anticline in western Hu-peh or the gorge district of the Yang-tze. It is interesting to compare this line of disturbance with the eastern edge of the Shan-si Plateau and the Great Khyngan

¹ Leclère, op. cit., pl. xiii.

² *Geogr. Journ.*, 1899, p. 639 et seq.

“step” by which Mongolia descends to Manchuria. They curiously reveal a harmonious relation, and may indeed be genetically related. In the vast area of South-Eastern China the rocks are generally folded in a north-easterly direction, reminding us of the structure of the north-eastern part of the country. What specially calls for our attention in this area is the zone of igneous activity which defines the south-eastern coast, and which is singularly parallel to the hypothetical line of disturbance along the eastern edge of the Kwei-chou Plateau as already discussed.

THE FUNDAMENTAL COMPLEX.

Rocks of extremely complex composition and structure are frequently reported to occur in Northern China. They form the greatest part of the Liao-tung and the Shan-tung peninsulas. Richthofen maps them as the “old gneiss and gneiss-granite”, and regards them as Archæan.¹ Rinne² and Lorenz, however, consider much of the so-called Archæan gneiss in Shan-tung as Algonkian granite. In other provinces of North-Eastern China schists and gneiss of very ancient type are often exposed in the mountain ranges. They are found, for instance, in the mountains to the west of the Liao-ho valley and in the neighbourhood of the great lava field of southern Mongolia. From the vicinity of the Wutai-shan (to the north of lat. 39° N., between longs. 112° 30' E. and 114° E.) they dive towards the south, and reappear in the lower parts of the mountain ranges that stand on both sides of the Fen-ho valley.

Further south a belt of Archæan gneiss runs along the northern foot of the Tsing-ling Range, and spreads itself out towards the east, namely, in the provinces of Ho-nan, northern An-hwei, and north-eastern Hu-peh. In these places the Archæan gneiss and schists sometimes rise as rugged mountains, and sometimes form plains partially covered by the “Hwang-tu” or the Loess.

In the north-western part of the Nan-shan Ranges, namely, in the principal chains lying to the south-west of the Da-ssue-shan or the Great-snow-mountain (extending from about lat. 40° N., long. 96° E. to the south-east), such as the Yema-shan, the Humboldt Mountain, and the South Tsaidam-ula or the Muschketov Range, Obrutchev found ancient gneiss and crystalline schists occurring in association with a variety of intrusive masses. The former class of rocks probably includes Archæan representatives.

The petrological characters of the above-mentioned Archæan rocks are so widely different from one another that a generalized description is hardly of any use. Suffice to say that they are not, as a whole, petrologically unlike the Lewisian of Great Britain and the Fundamental Complex of North America. Willis and Blackwelder, therefore, term the gneiss and schists that they observed in the

¹ *China*, vol. ii, p. 706.

² “Beitrag zur Gesteinskunde des Kiau-tschou”: *Zeits. d. d. geol. Ges.*, Aufsätze, pp. 122–67.

adjoining area of Chi-li and Shan-si and in the Tai-shan districts, western Shan-tung, the Tai-shan Complex. Further, they distinguish in the Tai-shan Complex at least three groups of rocks: the oldest consists of a chaotic mass of hornblende-schist, mica-schist, chlorite-schist, and other highly altered rock material that may have been derived from true aqueous deposits. In the Complex are found large intrusive bosses of acid composition, accompanied by offshoots of pegmatite, aplite, quartz-veins, etc. These are in general highly altered or strained. The youngest is a group of basic dykes, which are sometimes metamorphosed into true schist and sometimes remain unaltered.

In Southern China old gneiss and schist that can be definitely attributed to the Fundamental Complex are so far unknown. Schists and gneiss are reported to occur in the coast of Fu-kien¹ among the igneous intrusions and extrusions. But sufficient data are not yet available for the determination of their stratigraphical position.

(*To be continued.*)

The Lower Carboniferous Chert Formations of Derbyshire.²

By H. C. SARGENT, F.G.S.

(PLATE IV.)

INTRODUCTION.

THE origin of chert has of late been discussed with renewed activity, especially in American scientific journals. Difference of opinion centres mainly round the question of the source of the silica; whether it is of direct inorganic origin, or the result of the solution and redeposition of organic silica. Further points at issue relate to the age and formation of the chert; whether it is an original deposit contemporaneous with the country rock, or a metasomatic replacement of the latter and therefore of later age.

The object of this paper is to discuss the evidence afforded by the chert formations of Derbyshire, and to state the conclusions which are believed to be indicated as to their origin. Such conclusions are, in brief, as follows:—

(1) The cherts of Derbyshire are believed to be of direct inorganic origin, and not derived to any considerable extent, if at all, from organic silica.

(2) They appear to have been mainly deposited contemporaneously with the country rock, and are not, except to a limited extent, a metasomatic replacement thereof.

Rare occurrences are of later age.

¹ Ishii, "The Geology of the Yang-tze Valley": *Bull. Imp. Geol. Surv. Japan*, vol. xxiii, No. 2.

² This paper is the substance of one read before the Geological Society of London, February 25, 1920, publication of which was declined (*Abs. Proc. Geol. Soc. Lond.*, No. 1,051, pp. 47-8). Some additional evidence is now introduced.

GENERAL DESCRIPTION.

The chert of Derbyshire occurs mainly in the upper beds of the Carboniferous Limestone throughout the entire outcrop, and also in the clays and thin limestones passing up into the Limestone Shales. The chert-bearing limestone is usually thin-bedded, dark or black in colour, and belongs to subzones D_3 and D_2 of Vaughan's classification.¹ Sporadically, feeble developments are found in the massive, white or pale D_1 limestone at a considerable distance below the main beds.

Sometimes, especially in the northern part of the outcrop, the main chert-bearing limestone is pale-grey or white, and loses its thin-bedded character.

The chert occurs either as rows of nodules of very varying size and shape, or as tabular sheets up to 8 or 10 inches thick and of considerable horizontal extension. Rarely it may be seen filling vertical fissures or joints in the limestone.

A feature that has an important bearing on origin is the frequent change of horizon at which the chert-bearing limestone sets in. In the neighbourhood of Matlock, Cromford, and Crich it is only from 50 to 60 feet thick, but near Middleton Moor, about 2 miles south-west of Cromford, it sets in 150 feet lower, replacing pale, massive, chertless limestone. At Ashover the thickness is about 150 feet and on the western side of the massif it may attain 400 feet.² Between Longstone and Buxton the chert-bearing beds are 450 feet thick.³

The transition from the pale, massive limestone to the overlying dark, thin-bedded, chert-bearing rock is usually extremely abrupt.

In addition to the main chert deposits described above, there are other occurrences distinctly local in distribution which require separate mention. They are found mainly in the neighbourhood of Bakewell and to the west and north-west of that town, at Ashford and near Longstone Edge. These cherts consist of massive beds sometimes 8 or 9 feet thick, and they are usually white or grey without any relation to the colour of the associated limestone.

Similarly, on the north-west of Crich Hill there is a development of massive, brown chert of which 6 feet in thickness are exposed, but the base is not seen. It can be traced round the north side of the hill, and reappears on the east near the Old End Mine.

It is believed that these beds of massive chert owe their silica to a different source from that of the main chert beds.

In colour the cherts, other than the massive beds just referred to, generally bear a close relationship to that of

¹ Cf. "The Geology of the Northern Part of the Derbyshire Coalfield": *Mem. Geol. Surv.*, 1913, pp. 13-14.

² Most of these details of thickness are taken from "The Geology of the Northern Part of the Derbyshire Coalfield": *Mem. Geol. Surv.*, 1913, p. 20.

³ T. F. Sibly, "The Faunal Succession in the Carboniferous Limestone of the Midland Area": *Quart. Journ. Geol. Soc.*, vol. lxiv, 1908, p. 38.

the associated limestone. It varies from white to grey, blue and black, being as a rule, but no means always, darkest in the darkest limestone. The pigmenting agent appears, without doubt, to be generally organic carbon. The following partial analyses of five specimens of Derbyshire chert have been kindly prepared by Dr. H. F. Harwood and Mr. S. Young, of the Imperial College of Science and Technology. Owing to the varying amounts of limestone inclusions and calcareous organisms in most cherts, complete analyses possess little value.

	I	II	III	IV	V
Fe (as Fe_2O_3)	0.02	0.60	0.05	0.42	0.26
CO_2	Not est.	—	Not est.	0.40	1.66
Org. C	—	0.09	0.32	0.54	0.33

- I. White massive chert, Ashford.
- II. Brown massive chert, Crich Hill.
- III. Black nodular chert, Dale Quarry, Wirksworth.
- IV. Black nodular chert, Klondyke Quarry, Crich.
- V. Pale-grey nodular chert, Intake Quarry, Middleton.

These analyses show a consistent relationship between colour and percentage of carbonaceous matter, except in No. V, a pale-grey rock, in which the carbon is segregated into minute flakes visible under a pocket-lens.

The percentage of iron does not show the same consistent relationship to colour except in the case of No. II, a brown chert nearly free from other impurity. It is not, however, uncommon to find black nodules with the weathered surface oxidized to a rusty brown. It is, therefore, possible that ferrous iron may sometimes be the colouring agent.¹

EVIDENCE OF CONTEMPORANEITY.

All the tabular sheets of chert are conformably interstratified in the limestone with which they are associated. They are never transgressive. When the thickness of a bed varies, swelling or contracting, as is often the case, within a short distance, the bedding planes of the overlying rock always conform to the surface of the chert. Similarly, the rows of nodules are always aligned parallel to the bedding of the limestone. Isolated nodules often occur between the rows, but this is not a case of transgression.

When lenticular or current bedding of the limestone has taken place, converging rows of nodules or thin sheets of chert may be seen following the bedding planes. Good examples of this feature occur in Intake Quarry near Middleton, in Wensley Dale, and in Bradwell Dale.

The nodules usually occur in solid limestone away from partings. In vertical section their longer axes are almost always parallel to the bedding. When they occur in laminated, shaly limestone the

¹C. S. Garnett has shown that the colour of "Blue John" is due to bituminous matter (*Trans. Chem. Soc.*, vol. cxvii, 1920, pp. 621-3).

bedding lines of the overlying rock curve over the nodules, showing clearly that the latter were in situ before it was deposited (Fig. 1).

Under similar conditions the bedding lines of the rock below a nodule are disturbed to conform with the irregular under-surface of the nodule (Fig. 2). The last feature appears to prove that the chert had consolidated more rapidly than the calcareous ooze into which it was pressed down.

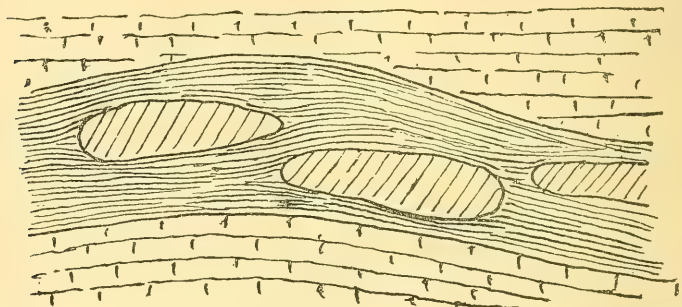


FIG. 1.—Chert-nodules in shaly, laminated limestone, Shiningbank Wood, near Alport. Solid limestone above and below the shaly bed.

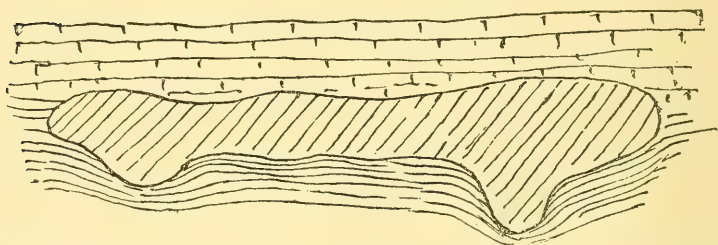


FIG. 2.—Chert-nodule, Lovers' Walk, Matlock Bath. Solid limestone above, shaly, laminated limestone below the nodule.

Cracks in the nodules, or sheets, are often filled with limestone, which appears to be obviously contemporaneous with the enclosing rock.¹

It may often be seen that the upper surface of a sheet of tabular chert is quite level, as if spread out by currents, and contrasting strongly with the irregular lower surface. A rough flow-structure may sometimes be seen in thin sections.

Contemporaneity is not claimed for chert filling fissures or joints in the limestone. Such occurrences are rare in Derbyshire, and they appear to be clearly of later formation. In the few instances

¹ Cf. W. A. Tarr, "Origin of the Chert in the Burlington Limestone": *Amer. Journ. Sci.*, vol. xlv, 1917, p. 422.

noted by me, crystalline calcite is associated with the silica in the fissure.

PETROLOGY OF THE SILICA.

It is generally recognized that the silica composing chert was originally in colloidal form. It has subsequently passed over mainly into crypto- or microcrystalline material, but a more coarsely crystalline development (quartz or chalcedony) is also of common occurrence.

Lindgren¹ points out that the work of Heim, Leitmeyer, and others leads to the conclusion that chalcedony is in all cases composed of quartz fibres, and that it always results from crystallization of gelatinous silica, which may, in becoming crystalline, either turn into granular quartz or into fibrous quartz, i.e. chalcedony.

Impurities in the silica appear to have had a marked effect on its crystallization. In the dark-coloured or black cherts the development is mainly crypto- or microcrystalline, but small areas, of varying shapes, may often be seen in thin sections from which the impurities appear to have been drawn off by segregation, or which have, perhaps, been left clear by differential absorption. In the clear central portion of such areas granular quartz has formed. On the outer margin of the quartz there is usually a narrow zone of fibrous quartz (chalcedony), often in the form of radial aggregates. Its refractive index is always a little lower than that of the granular quartz (Becke's test). Outside this zone, in the more highly pigmented matrix, the silica is crypto- or microcrystalline.

When viewed in thin section by transmitted light, the chalcedony is frequently, but not always, of a pale-brown colour. Pirsson² has shown that this colouration, which often occurs in felspar-spherulites in acid lavas, may be an optical phenomenon due to absorption of the blue rays in passing through angular fibres or scales of a colourless mineral; the finer the fibres the greater being the absorption. This is, perhaps, often the case in the rocks under discussion, but the chalcedony is also frequently coloured by a ferruginous or bituminous pigment, which is occasionally concentrated in concentric bands (Pl. IV, Fig. 1).

It is noteworthy that in the purer cherts, nearly or quite free from colouring matter, although some of the silica may remain in the cryptocrystalline state, there is no chalcedony, but an extensive development of granular quartz.

Liesegang³ has shown that the presence of iron hinders crystallization in agates, and the foregoing considerations seem to justify the same conclusion in regard to impurities in chert.

¹ "Processes of Mineralization and Enrichment in the Tintic Mining District": *Econ. Geol.*, vol. x, 1915, p. 233.

² "On an Artificial Lava-flow and its Spherulitic Crystallization": *Amer. Journ. Sci.*, vol. xxx, 1910, pp. 101-2.

³ *Geologische Diffusionen*, 1913, p. 100.

EVIDENCE AGAINST METASOMATISM.

Much of the evidence already given in favour of contemporaneity is also obviously opposed to the theory that the chert is a pseudomorph. There are other considerations that tend in the same direction, although the microscope shows that a limited amount of replacement has generally taken place at the contact between chert and limestone. It is obvious, however, in thin sections that impurities have not only hindered crystallization, but also, to a large extent, replacement.

In the dark or black cherts the replacement is usually limited to a thin band of clear crystalline silica at the contact between chert and limestone or around calcareous organisms (Pl. IV, Fig. 2). The calcite of small organisms, perhaps as a result of freedom from impurity, is sometimes entirely replaced, but unsilicified calcareous fossils are very abundant. Dr. G. J. Hinde¹ called attention to these features as disproving the pseudomorph theory.

The contact between chert and limestone is usually quite sharp and often serrated (Pl. IV, Fig. 3). The nodules, when black, often break away from the enclosing rock with a clean fracture, making it difficult to obtain a hand-specimen showing the contact.

In the purer white cherts, on the other hand, there is usually no definite line of contact, but a broader transition zone in which the replacement reaction appears to have been active, and in which crystalline silica and calcium carbonate are intimately intermingled.

Wherever this partial replacement has taken place, the replacing material is clear crystalline silica, probably always in the form of minutely granular quartz. The impurities appear to be always excluded from the contact films of the solutions that take part in the reaction.²

It is significant that in the quartz-rock described by Dr. Bemrose,³ which, as he states, is clearly a replacement of limestone, there is no amorphous or cryptocrystalline silica, no chalcedony, and the replacing silica is all in the form of clear granular quartz.

The conclusion seems to be justified that the impure silica of these cherts, which remains in a crypto- or microcrystalline state, has taken no part in a replacement reaction with calcium carbonate.

If the pseudomorph theory be true, thin partings in laminated limestone, consisting of detrital terrigenous material (Fig. 1), should be repeated in the chert, since they would obviously not be replaced by the metasomatic reaction. There is no such repetition.

Minute grains of calcite may often be seen associated with the quartz in the partial replacement zone. This probably indicates that the consolidation of the silica took place before the calcite grains were completely replaced, and they were thus preserved from

¹ "Organic Origin of Chert": *GEOL. MAG.*, 1887, p. 445.

² Cf. Lindgren, *Mineral Deposits*, 1913, p. 671; also Tarr, *op. cit.*, p. 415.

³ "On a Quartz-rock in the Carboniferous Limestone of Derbyshire": *Quart. Journ. Geol. Soc.*, vol. liv, pp. 169-83.

further action by the solutions. Other evidence leading to the conclusion that the chert was consolidated more rapidly than the limestone has already been given, and it is clear that rapid dehydration and consolidation would quickly limit replacement.

Professor A. H. Church,¹ in his well-known experiment, found that gelatinization of silica stopped the reaction between silicic acid and calcium carbonate if the concentration of silica in the solution exceeded 0.15 per cent.

The occurrence of chert in the clays at the top of the limestone shows that replacement is not an essential feature of its formation.

The invariable conformity of the limestone with the sheets of tabular chert, even to small details of undulating surfaces, appears to be quite inconsistent with the view that the chert is a pseudomorph.

EVIDENCE AGAINST THE SPONGE-SPICULE THEORY.

The theory of the solution and redeposition of organic silica, although nearly unanimously rejected by recent American investigators, still finds support among English geologists.² It is proposed to examine the conflicting evidence.

It seems clear that these extensive contemporaneous beds of chert were rapidly formed, and it is admitted by supporters of the theory that an agent capable of effecting the solution, and likely to be present in the sea, is unknown.

Remains of unsilicified calcareous organisms, as already noted, are abundant in the chert, and hence it is clear that acids generated by decaying organic matter were of no great importance as solvents.

The alkaline reaction of sea-water above a calcareous ooze is believed by some³ to be capable of dissolving organic silica. This may, perhaps, be the explanation of the replacement of sponge spicules, more or less completely, by calcite in limestone, but never in a cherty matrix.⁴ It seems certain, however, that a considerable period of time would be required for the process. The solution actually observed in sponge-spicules from modern dredgings is limited to a widening of the axial canal and the disappearance or thinning of more delicate processes.⁵

Spicules, of which the amorphous silica has become crystalline, are abundant in many thin sections of both chert and limestone, and it seems obvious that if solutions capable of dissolving organic silica were present to the extent necessitated by the theory, it is hardly likely that any spicules would be preserved.

¹ "Observations on Silica": *Journ. Chem. Soc. Lond.*, vol. xv, 1862, p. 109.

² Cf. E. E. L. Dixon, *Abs. Proc. Geol. Soc. Lond.*, No. 1,051, 1920, p. 49.

³ Cf. E. F. Davis, "The Radiolarian Cherts of the Franciscan Group": *Univ. Cal. Pub. Bull. Dep. Geol.*, vol. xi, 1918, p. 366.

⁴ Cf. G. J. Hinde, "On Beds of Sponge Remains in the Lower and Upper Greensand of the South of England": *Phil. Trans.*, pt. ii, 1885, p. 431.

⁵ Murray and Irvine, "On Silica and the Siliceous Remains of Organisms in Modern Seas": *Proc. Roy. Soc. Edin.*, vol. xviii, 1891, p. 231.

Davis¹ calls attention to the very important point that the radiolarian earths of Barbados are believed to represent true deep-sea siliceous oozes, yet there is no evidence of the solution of silica on the sea-floor, and these siliceous organic remains have not been converted into chert. He also points out that the white diatomaceous earths of the Monterey group in California, which must have been associated with much organic matter, are almost unconsolidated and show no evidence of solution.

Dr. F. W. Clarke² states that the silica extracted from the ocean by radiolarians, diatoms, and siliceous sponges "is finally deposited on the sea-floor and does not redissolve, or at least not readily". He adds: "The insolubility of silica in sea water is great but not absolute."

SOURCE OF THE SILICA.

The formation of chert by direct chemical precipitation of inorganic silica held in solution in sea-water, which is supported in this paper, has found many advocates in the past. Among these may be mentioned Hull and Hardman,³ Prestwich,⁴ and, more recently, Tarr,⁵ Van Tuyl,⁶ and, in part, Twenhofel.⁷

Upwards of 319,000,000 metric tons of dissolved silica are annually contributed to the sea in colloidal form by the rivers of the world.⁸ Yet the amount present in normal sea-water is practically *nil*. This fact clearly indicates, as Tarr⁹ and Twenhofel¹⁰ point out, the completeness of the precipitation.

Within the area of the deposition of muds and fine silts the dissolved silica appears to be carried down and to form a large part of the colloidal constituent, giving plasticity to clays.¹¹ Ashley has shown in an important paper that the colloidal matters of clay are "non-crystalline, hydrated, gelatinous, aluminum silicates, organic colloids, gelatinous silicic acid, and hydrated ferric oxide".¹²

Dr. W. T. Gordon has kindly pointed out to me that E. C. Barton¹³ has shown the importance of colloids, acting as an agglutinant, in the formation of sandbanks and deltas. He states:

¹ Op. cit., p. 370.

² *The Data of Geochemistry*, 1916, p. 130.

³ "On the Nature and Origin of the Beds of Chert in the Upper Carboniferous Limestone of Ireland": *Sci. Trans. Roy. Dub. Soc.*, vol. i, 1878, pp. 71-94.

⁴ *Geology, Chemical, Physical, and Stratigraphical*, vol. ii, 1888, pp. 320-4.

⁵ Op. cit., p. 427 et seq.

⁶ "The Origin of Chert": *Amer. Journ. Sci.*, vol. xlv, 1918, p. 456.

⁷ "The Chert of the Wrexford and Foraker Limestones along the State Line of Kansas and Oklahoma": *Amer. Journ. Sci.*, vol. xlvii, 1919, pp. 407-29.

⁸ F. W. Clarke, *Data of Geochemistry*, 1916, pp. 115-16.

⁹ Op. cit., p. 429.

¹⁰ Op. cit., p. 417.

¹¹ Cf. Leith and Mead, *Metamorphic Geology*, 1915, p. 104.

¹² "The Colloid Matter of Clay and its Measurement": *U.S. Geol. Surv. Bull.* 388, 1909, p. 12.

¹³ "The Work of Colloids in Sandbank and Delta Formation": *Geogr. Journ.*, vol. li, 1918, pp. 100-12.

"Professor E. W. Hilgard found, at the mouth of the Mississippi, a 15 feet layer of colloidal jelly on the ocean side of the bar. He ascribes its formation to the precipitation of the fine colloidal particles by the mixing of the river waters with the salt water" (*Pop. Sci. Monthly*, March, 1912). I have been unable to obtain access to Professor Hilgard's paper.

The effectiveness of the ions of bivalent elements in causing flocculation has been shown to be much greater than that of univalent ions, and it has been conclusively proved experimentally that colloidal silica is rapidly flocculated and precipitated by calcium carbonate in presence of carbon dioxide.¹

In a sea in which deposition of calcium carbonate was continuously taking place simultaneously with the products of land-erosion, as was the case when the impure chert-bearing limestones of Derbyshire were laid down, there can be little doubt that dissolved silica would be contributed to the sea, and that it would be precipitated near the land when a sufficient concentration had taken place. The tendency of silica to form supersaturated solutions is an important point.

The purer white, or pale, lower limestone, in which chert occurs sparingly and sporadically, was probably formed in a clear sea, not necessarily far from land, but under conditions when the contribution of dissolved silica, or other terrigenous material, was exceptional and not the rule.

The liberation of silica by carbonation of silicates would be greatly increased, as was pointed out by Prestwich,² and more recently by Van Hise,³ if the area undergoing denudation consisted of basic igneous rocks. The abrupt transition in many parts of Derbyshire from the pale or white limestone to the overlying, impure, chert-bearing rock is very noteworthy, and would, of itself, suggest that movement, resulting in an increase of terrigenous deposits, had taken place. This view is strongly supported by the presence, as observed in the field, of small unconformities and thrusts, and occasional current-bedding.⁴

The toadstones of Derbyshire often underlie the main chert-bearing rock at no great distance, and it is suggested as very probable that some, perhaps a large part, of the sea-floor covered by these submarine flows was raised above sea-level by disturbance, and was thus brought within the range of atmospheric and chemical erosion. There seems, therefore, to be fair evidence that, during the deposition

¹ Cf. Dean, "The Formation of Missouri Chert": *Amer. Journ. Sci.*, vol. xlv, 1918, p. 413. Also Tarr, *op. cit.*, pp. 434-6.

² *Op. cit.*, p. 324.

³ "A Treatise on Metamorphism": *U.S. Geol. Surv. Mon.* 47, 1904, p. 824. See also Van Hise and Leith, "The Geology of the Lake Superior Region": *U.S. Geol. Surv. Mon.* 52, p. 505.

⁴ Cf. T. F. Sibly, *op. cit.*, p. 63 and fig. 5 (p. 62). Also C. B. Wedd, "The Geology of the Northern Part of the Derbyshire Coalfield": *Mem. Geol. Surv.*, p. 35, 1913. The author has noted unconformities in other parts of the limestone massif.

of the main chert-bearing limestone, a large supply of dissolved silica was available for the formation of chert. The variations in the horizon at which the chert-bearing limestone sets in, as noted above, may be attributed to differential movement on the sea-floor.

There is abundant evidence of the simultaneous precipitation of silica and calcium carbonate. At Knivetonwood, about three miles north of Ashbourne, nodules of black chert, in clays at the top of the limestone, have a brown rind, from $\frac{1}{4}$ to $\frac{3}{8}$ in. thick, consisting of an intimate admixture of calcium carbonate and cryptocrystalline silica, the latter being present in one specimen examined to the extent of 14 per cent. The limestone associated with chert in the same quarry weathers brown like a sandstone. In a specimen of this rock the insoluble residue, consisting largely of cryptocrystalline silica, amounted to 39.5 per cent. In the Black Marble Quarry, at Ashford, there is a strong development of black chert in thin sheets, on which there is a black calcareous rind similar to that on the Knivetonwood nodules.

The colour-relationship between chert and limestone, resulting from similar impurities, and the nearly simultaneous setting in of the chert with the change of character of the limestone, at whatever horizon the change takes place, are further indications of the close connexion between land-denudation and chert-formation.

A feature very often seen in thin sections of chert is the presence, often in great numbers, of minute rhombs of dolomite or chalybite, the latter often oxidized to opacity. The absorptive property of colloids affords a simple explanation of the presence in the colloidal silica of metalliferous salts, the products of contemporaneous chemical denudation, which have subsequently crystallized out as dolomite or chalybite. It is difficult to understand how this feature can be reconciled with the sponge-spicule theory. Further, the chert in which the rhombs occur is sometimes embedded in limestone, which is not dolomitized, and contains no rhombs. This feature seems quite inconsistent with the theory that the chert is a pseudomorph.

The occurrence of chert in nodules, of very varying shape and size, and often with patches of limestone enclosed, points to segregation subsequent to precipitation. Twenhofel¹ observes that the dominating factor in nodule-growth was the attraction exercised on the dissolved silica by the growing nodule. The occurrence of a calcareo-siliceous rind on nodules or sheets suggests that there was a heavy simultaneous precipitation of calcium carbonate, and that diffusion of the silica was arrested by dehydration and consolidation.

The variation in vertical spacing between different rows of nodules or sheets, ranging from a few inches to several feet, suggests variation in the time required to effect a sufficient concentration of silica

¹ *Op. cit.*, p. 427.

for precipitation, owing to differential denudation. This feature would be difficult to explain under the sponge-spicule theory.

Davis¹ has shown experimentally that when a suspension of finely divided clay was mixed with a solution of sodium silicate, the addition of ammonium carbonate caused flocculation of silicic acid and formation of gelatinous silica. The silica and clay were segregated into alternate layers, and it is interesting to note that the experiment produced many of the features of the bedding of chert, such as nodules, irregular thinning and thickening of bands and lens-like terminations.

The massive cherts, referred to above, which are of purely local occurrence, now require consideration. These rocks, so far as existing exposures show, occur solely in the neighbourhood of former volcanic activity. Near Bakewell they are closely associated with the Cracknowl (or Crackendale) vent, and they overlie the lava of that district. At Crich there is a bed of lava in the hill, at some distance below the chert. Wherever they occur they are seen on one horizon only, and are not repeated again and again through a considerable thickness of limestone, as is the case with the main chert beds. It would appear that the supply of silica was continuous till it was exhausted.

The absence or paucity of organic colloids (see Analyses I and II) is a noteworthy feature, distinguishing these rocks from the main chert beds. The result appears to be that, in colour, they show no relationship to the associated limestone. White is the prevailing colour, but grey beds are often interspersed. The Crich rock is brown, owing to admixture of iron. Not infrequently the rock has the appearance of a sinter, resembling the present-day deposits of hot springs. Fluorite is frequently associated with these cherts, as it is with quartz-rock. It occurs as the infilling of cavities and veins, and in minute grains scattered through the rock and in the associated limestone. At Ashford, a specimen of limestone from a parting in the chert contained 0.36 per cent of insoluble residue, which consisted of amorphous fluorite with a little cryptocrystalline silica.

Fossils are rare in these cherts. That organisms were sometimes entangled in the silica is rendered probable by the occasional occurrence of flakes and small concretions of carbonaceous matter, but it is rarely that any trace of the organism remains.

As with the main cherts, so, too, with those under consideration, simultaneous precipitation of silica and calcium carbonate has often taken place. Streaks and patches of limestone are common in thin sections, their margins usually showing signs of replacement (Pl. IV, Fig. 4), and short discontinuous bands, 3 or 4 inches thick, may be seen in the body of the rock.

¹ *Op. cit.*, pp. 399-401.

The lava-flows underlying these beds have suffered intense decomposition, which must have liberated large quantities of silica. It has been shown elsewhere¹ that the orthoclase and albite molecules were conspicuously present. Lindgren² states that in the great geyser regions of Yellowstone National Park, New Zealand, and Iceland the predominating springs "are essentially sodium chloride waters with large amounts of silica, believed to exist in part as sodium silicate, a large quantity of free carbon dioxide, and a little hydrogen sulphide". "The waters are always hot and usually ascend through volcanic rocks."

The features of the massive cherts of Derbyshire, which distinguish them from the main cherts, suggest a different origin, and it is believed that pneumatolytic discharges from the cooling lava-flows, or juvenile waters, the expiring manifestations of volcanic activity, may have carried similar salts and been the direct source of the silica of which they are composed.³ It is suggested that these rocks may, for distinction, be conveniently named "magmatic cherts".

BANDING OF THE CHERTS.

In all the cherts a banding, consisting of alternate light and dark layers, is not infrequently seen. In the nodules the bands are generally concentric or parallel with the outer surface. In the tabular cherts they are usually parallel with the bedding planes. This feature appears to be the result of a segregation or rhythmic precipitation of impurities in the course of dehydration. The light bands often consist of clear silica, apparently free from impurities. "Alternating segregation of silica and calcite," as noted by Mr. Dixon,⁴ has not been observed by me in the Derbyshire cherts.

A feature that may often be noticed in thin sections is the presence of a thin bituminous band, or string, following the line of contact between chert and limestone (Pl. IV, Fig. 3). Similar strings sometimes occur in the body of the limestone itself. Dr. Sorby⁵ called attention to this feature in limestone from Stony Middleton.

So far as can be judged from thin sections and hand-specimens, the bituminous material belongs to the limestone and not to the chert. Sometimes, when there is no definite band, the limestone shows a distinctly greater depth of colour in the neighbourhood of the contact. Moreover, the band sometimes occurs at the contact between white chert, free from carbonaceous matter, and dark,

¹ H. C. Sargent, "On a Spilitic Facies of Lower Carboniferous Lava Flows in Derbyshire": *Quart. Journ. Geol. Soc.*, vol. lxxiii, 1918, pp. 11-23.

² *Mineral Deposits*, 1913, p. 52.

³ Cf. Dewey and Flett, "On some British Pillow-lavas and the Rocks associated with them": *GEOL. MAG.*, 1911, p. 245. Also Flett, "The Iron-ore Deposits of Nobblehouse and Garron Point and their Genesis" (*Edin. Geol. Soc.*) Abstract in *GEOL. MAG.*, Vol. LVI, 1919, p. 92.

⁴ *Loc. cit.*, p. 50.

⁵ "On the Application of Quantitative Methods to the Study of the Structure and History of Rocks": *Quart. Journ. Geol. Soc.*, vol. lxiv, 1908, p. 225.

obviously impure, limestone. This feature may, perhaps, be due to a draining-off of carbonaceous matter in the limestone in the course of dehydration, and, if so, it is obvious that its migration would be arrested at the contact with the more rapidly consolidated chert.

CONCLUSION.

It is believed that the foregoing evidence justifies the view, expressed at the commencement, that the cherts of Derbyshire are mainly of direct inorganic origin and contemporaneous with the associated limestone and clays. It is, however, possible that siliceous organisms have furnished a subsidiary source of supply, since dredgings show that organic silica is not absolutely insoluble in sea-water. It is thought, further, that the evidence shows that the chert is not a metasomatic replacement of the limestone, except to a very limited extent.

The existence of large beds composed of siliceous organisms which have not been dissolved (p.272) is a point that cannot be ignored by advocates of the organic theory.

Although the Derbyshire cherts alone have been discussed, it is believed that the same conclusions will be found to apply to other areas. I had an opportunity last summer of making a brief examination of the fine deposits of chert in North Flintshire, which are said to extend through a thickness of 350 feet, and have been erroneously described as being without intervention of limestone.¹ At the Pentre Quarries, near Gronant, the chert occurs as tabular sheets in thin-bedded, siliceous, black limestone, the occurrence being similar to that of the beds described above at Ashford, and elsewhere in Derbyshire. After further field-work I hope, with the editor's permission, to discuss these Flintshire cherts on another occasion.

I have to thank Dr. H. H. Bemrose for kindly allowing me to examine his thin sections of chert and for much useful information as to exposures; also Dr. H. H. Thomas for kindly permitting me to examine thin sections in the collection of the Geological Survey. The interest taken by Dr. H. F. Harwood in the colour-problem has been of great service.

P.S.—Since the foregoing paper was written Mr. W. Alfred Richardson's interesting article² on "The Relative Age of Concretions" has appeared. The arguments in that paper seem to be mutually destructive. In Mr. Richardson's opinion, "conformity of stratification lines [round a concretion] is caused in every case by concretionary growth."³ In the case of chert-nodules he holds to the replacement theory, and he fixes the date of their formation as "at the earliest later than the first compacting of the matrix".² In this case Lindgren's law of equal volumes would

¹ G. J. Hinde, "Organic Origin of Chert": *GEOL. MAG.*, 1887, p. 445.

² *GEOL. MAG.*, March, 1921, pp. 114-24.

³ *Ibid.*, p. 118.

apply,¹ and since the matrix must have been removed as fast as the "growing nodule" grew, it is clear there would be no deformation of the surrounding beds!

Mr. H. L. Hawkins² has effectively disposed of the argument that contemporaneous concretions are never surrounded by conformable stratification lines, and it is only necessary to recall the high angle of rest, often exceeding 50 degrees, of rock-fragments on the seaward face of a coral reef, to realize that, whatever may be the results of laboratory experiments, nature does not support Mr. Richardson's view of gravitational effects on the sea-floor.

In attacking the chert-problem it is useless to deal with the nodules separately from the extensive tabular sheets which are often extremely well-bedded; a similar origin and relative age must undoubtedly be ascribed to both. Moreover, the "nodules" themselves, as seen on a vertical face of limestone, are very often merely transverse sections of branching ramifications of a large mass of chert in the interior of the rock, and not individual concretions, either spherical or ellipsoidal.

I owe Mr. Richardson many thanks for much strenuous criticism, which has been very helpful in the formation of my own views.

EXPLANATION OF PLATE IV.

(The figures are all taken from slides in the author's collection.)

FIG.

- 1.—Blue Nodular Chert, Nimble Jack, Via Gellia. Ordinary light, $\times 25$ diams. (slide 565*b*). The central, white area, of irregular shape and free from impurity, consists of granular quartz. Outside the quartz fibrous chalcedony, in spherulitic aggregates, is developed in a zone of silica apparently coloured by impurity. Outside this zone the silica is crypto- or microcrystalline.
- 2.—Black Nodular Chert, Nutseats Quarry, near Haddon Hall. Nicols crossed, $\times 25$ diams. (slide 577*a*). The thin, white bands are microgranular quartz, enclosing unreplaced calcareous material. In the lower left-hand portion of the figure part of the section of a coral is seen, the wall and septa being unreplaced. Granular quartz fills the spaces between the septa. The groundmass is mainly crypto- and microcrystalline silica. Oxidized crystals of a ferri-ferous dolomite or chalybite are seen in the figure.
- 3.—Black Nodular Chert, Klondyke Quarry, Crich. Ordinary light, $\times 20$ diams. (slide 439). The black portion of the figure is limestone. The contact between chert and limestone is marked by a thin, bituminous black band.
- 4.—Magmatic Chert, Pretoria Mine, Bakewell. Nicols crossed, $\times 25$ diams. (slide 573). All the silica in the section is in the form of granular quartz. The mottled grey material is unreplaced limestone.

¹ "The Nature of Replacement": *Econ. Geol.*, vol. vii, 1912, p. 529.

² *Geol. Mag.*, April, 1921, p. 192.



FIG. 1. $\times 25$.



FIG. 2. $\times 25$.

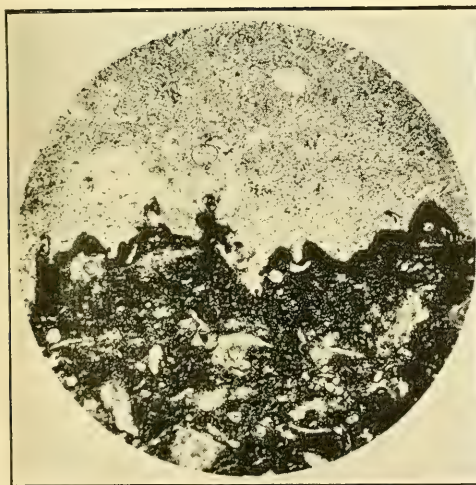


FIG. 3. $\times 20$.

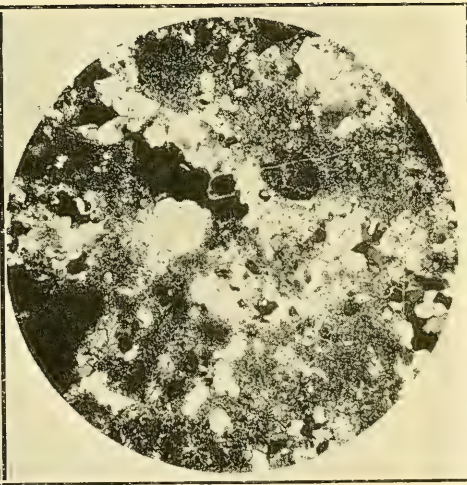


FIG. 4. $\times 25$.

Photo

G. S. Sweeting.

[To face p. 278.]

REVIEWS.

THE PLATINUM METALS. By A. D. LUMB. Imperial Institute Monographs, pp. ix + 63, with 1 map. London: Murray. 1920. Price 3s. 6d. net.

THIS publication forms one of the useful series of monographs on metals issued by the Mineral Resources Committee of the Imperial Institute. It comprises a full account of the world's resources, so far as known, of the metals platinum, palladium, iridium, osmium, ruthenium, and rhodium. Owing to the disturbed state of Russia and the collapse of the platinum supply, much prospecting has been carried out in other lands, but without great success. The author of this monograph has evidently followed up with great care all recent available information on the subject, and has produced a very complete account of the present state of our knowledge. Duparc's great work was, of course, not published when he wrote, but he has compiled a very good account of the platinum deposits of the Urals. Incidentally, we are pleased to see that Russian names are correctly transliterated, instead of the irritating germanized and gallicized versions that are commonly current in geological literature. To British geologists some of the most interesting occurrences of platinum are those found in association with the nickeliferous sulphides of Sudbury, Inisawa, and elsewhere. In 1918 Ontario produced nearly 5,000 troy ounces; this seems to occur as sperrylite, which is the only known native compound of platinum.

On p. 38, near the middle, we do not think that the author really means that the country rock largely consists of *olivinite*. This somewhat hypercritical remark may be permitted, since we have found the work very free from errors.

A SERIES OF NETS FOR THE CONSTRUCTION OF MODELS ILLUSTRATIVE OF THE SIMPLE CRYSTALLINE FORMS. By JAMES B. JORDAN. London: Thomas Murby & Co. 1921. Price 3s. net.

AS access to a set of suitable models is essential for the study of crystallography, and as models in wood are somewhat expensive, it is often helpful for the student to make use of cardboard models which he can easily construct for himself with the aid of nets, i.e. outlined drawings of the crystal faces, printed on paper or cardboard, and so arranged that they can be cut out and folded up to represent the form required.

A set of 41 nets originally drawn and published some fifty years ago by Mr. James B. Jordan, has recently been re-issued by Messrs. Murby & Co. This re-issue is welcome, and most of the nets will still be found useful, but in the interval which has elapsed since they first appeared, crystallography has made notable advances, and

a series which was adequate in 1870 is no longer as representative as is desirable. Thus, while nets of the commoner simple forms of the cubic system are given, those of the important trapezohedral form of this system—the pentagonal icositetrahedron and the tetrahedral pentagonal dodecahedron—are lacking. Similar lacunæ are found in the tetragonal and rhombohedral systems. No cubic combinations are given, and the nets of oblique and anorthic crystals illustrate a nomenclature now obsolete and could be profitably replaced by others representing actual crystals of common substances such as orthoclase, gypsum, and copper sulphate, belonging to these systems. It is to be hoped that the publishers of this series may some day see their way to giving us a revised and extended set of nets fully illustrative of modern crystallography.

THE IGNEOUS ROCKS OF ENCOUNTER BAY. By W. R. BROWNE.
Trans. Roy. Soc. S. Australia, vol. xlv, 1920. pp. 1-57, with
4 plates.

THIS communication is an important contribution to igneous petrology, and adds a distinct chapter to the history of igneous action in South Australia.

The igneous rocks of Encounter Bay comprise two related series, (a) a plutonic series, consisting of quartz mica diorite, adamellite, potash granite, and albite mica syenite, and (b) a series of minor intrusions consisting of uralitic dolerites, potash aplites, soda aplite, and granophyre. The whole assemblage of rocks is to be regarded as a plutonic complex, the component members of which have been successively and more or less independently injected into their present positions from an underlying magma reservoir. The sequence of intrusion in the plutonic series is (1) quartz mica diorite, (2) adamellite, (3) potash granite, (4) albite mica syenite, the last-named rock being considered as an end product of differentiation. The facts of intrusion are best explained as due to a differentiation brought about in the underlying magma basin by fractional crystallization with sinking of crystals.

The suite of minor intrusions is considered as derived by complementary differentiation from a magma of composition closely comparable to the dominant adamellite type. The aplitic members of this complementary suite are completely free from ferromagnesian minerals. An interesting feature of the soda aplites is the development of a chequer twin structure in the albite felspar, a characteristic which appears to be widely developed in rocks of this class.

The plutonic complex is intrusive into a series of Lower Cambrian (or possibly late pre-Cambrian) sediments, which at the visible contact with the intrusive rocks are pelitic in character. The intrusions are considered to have accompanied the diastrophic movements which put an end to the Cambrian sedimentation.

A distinct metamorphic aureole surrounds the plutonic complex, and amongst the metamorphic products are andalusite and cordierite mica schists.

Pneumatolytic metamorphism of the country rocks, involving the introduction of Na_2O and TiO_2 , is strongly developed near the contact with the albite syenite. This metasomatism has resulted in the production of albite hornfels consisting of a fine-grained mosaic of quartz, albite, chlorite, and rutile. The syenite itself has not escaped metasomatic alteration, the biotite of both country rock and igneous rock being converted into chlorite.

The paper is furnished with seven complete rock-analyses, and the relations of a number of these are expressed in a variation diagram. The Encounter Bay suite of rocks forms an admirable illustration of an igneous rock series in which a progressive differentiation with increasing alkalinity is strongly emphasized.

C. E. TILLEY.

TOPOGRAPHIC MAPS AND SKETCH MAPPING. By J. K. FINCH, C.E., A.M. pp. 168. John Wiley & Sons. 13s. 6d.

THIS is an elementary book on sketch mapping, and only the appendix will have much interest for the geologist. The latter consists of a descriptive list of the topographic maps of the world, special attention being given to the less well known, such as those of South America. This list will be very useful for reference, and apparently has been collected with considerable care by the compiler, F. K. Morris.

THE SRIMANGAL EARTHQUAKE OF 8TH JULY, 1918. By MURRAY STUART, D.Sc. Mem. Geol. Surv. India, vol. xlv, 1920. pp. 1-70, 12 plates.

THE Srimangal earthquake of 1918 deserved the careful investigation bestowed on it by Dr. Murray Stuart, though it is not one that has added much to our knowledge of earthquake-phenomena. The principal sections of the report are those which deal with the nature and effects of the shock within successive isoseismal lines, the analysis of the seismograms at various observatories, the secondary earthquake that occurred four or five minutes later with its epicentre near Madura in Southern India, and the results of the re-levelling across the epicentral area in the Balisera valley and in part of the Doloi valley. The depth of the focus is estimated, by Dutton's method, at about 8 or 9 miles. During the winter of 1919-20 the Trigonometrical Survey repeated a series of levels, first carried out in 1911-12, along the line from Silchar to Comilla, which crosses the epicentral area nearly at right angles to its longer axis. A comparison of the two series of levels shows that no change took place in the area to the north-east of the epicentral axis, but that, on the other side, from the low range of hills 6 miles west of

Srimangal to a distance of 30 miles from that place, a settlement of from $1\frac{1}{2}$ to 9 inches has occurred. The author concludes that "there is little doubt that the earthquake was due to subsidence along the southern side of a normal fault cutting the rocks below the alluvium of the Sylhet district, and situated approximately under the major axis of the epicentral area". In Dr. Stuart the Geological Survey of India clearly possesses an officer who may be expected to deal adequately with the more interesting earthquakes which will probably occur before his term of service ends.

C. D.

LEAD ORES. By T. C. F. HALL. Imperial Institute Monographs on Mineral Resources. 127 pp., with a map and two diagrams. London: John Murray, 1921. 6s. net.

THE genesis and mineralogy of the ores of lead is a subject of great interest and importance in itself, and it also forms part of a much larger question, namely, the existence of a definite generalized succession in depth of primary ore-zones. This is evidently of great economic importance as well as of much scientific interest, if it can be established, owing to its bearing on the problem of a possible change in the metal-content of ore-deposits when followed downwards. Evidence is rapidly accumulating that such a definite succession will in all probability eventually be established, and the facts so clearly stated by the author of this memoir will doubtless be of very great assistance in clearing up the question. It is here demonstrated that in a normal lead-zinc-silver deposit the silver-content is highest at the top, while in depth ore with dominant lead commonly gives place to zinc. Whether this in its turn should give place to copper, as is believed by many, still remains to be proved, though there is a considerable mass of evidence in favour of this idea.

This memoir follows the lines laid down in the preceding members of the series, and the author has made excellent use of the large amount of information available, preserving a due balance and bringing out the points of special interest. The information given is clear, up to date, and concisely expressed, while the views stated on the origin of lead ores, in many cases a subject of controversy, are fair and temperate, as might be expected from the author's wide practical experience. He is to be congratulated on having well performed a somewhat difficult task.

GEOLOGY OF MESOPOTAMIA AND ITS BORDERLANDS. Compiled by the Geographical Section of the Naval Intelligence Division, Naval Staff, Admiralty. 116 pp., with 5 maps and 9 figures. Stationery Office, n.d. Price, 5s.

THIS is, we believe, the first comprehensive summary of the geology of a little-known part of the world. In addition to the geology of Mesopotamia, the book contains much information

about Arabia, Armenia, Kurdistan, and Persia. The pioneers of Persian geology, Ainsworth (1838) and Loftus (1853), made long journeys in Mesopotamia and Persia. They give clear accounts of the formations and are remarkably correct in their determination of age and relation, but it was left to later travellers, of whom De Morgan is the best known, to work out the structure of this part of the world. From the works of these explorers and geologists this book has been compiled, and we suspect that the author, whose name is not given, has an intimate knowledge of at least part of this country.

The first seven chapters deal with the stratigraphy, structure, and geological history of the area; the latter part with the economic geology. A great part of Mesopotamia is covered with alluvial deposits of the Tigris and Euphrates. The underlying beds are for the most part of Miocene or Pliocene age. In Mesopotamia proper the oldest rocks exposed are Cretaceous, but in Kurdistan, Armenia, and Persia Jurassic, Permian, Carboniferous, Devonian, and Lower Palæozoic occur. Some granites and metamorphic rocks are referred to Archæan. Igneous rocks of Pliocene age also occur.

The most interesting and best known formation is the gypsiferous series, known in Persia as "Lower Fars". It crops out over a large part of Northern Mesopotamia and in South-West Persia chiefly in anticlines. In Armenia similar beds were described by Oswald. With regard to the age of these beds there is much difference of opinion, as Oswald correlates them with Tortonian, and Pilgrim in Southern Persia considers them Helvetian or Burdigalian. This is fully discussed pp. 77-83. Since this book was written, *Ostrea latimarginata*, which is looked upon as a zone fossil of the Burdigalian by the Indian palæontologists, has been found in the Lower Fars of Mesopotamia. This supports Pilgrim's views expressed in "The Geology of the Persian Gulf and adjoining portions of Persia and Arabia", *Mem. Geol. Surv. India*, vol. xxxiv, pt. iv, p. 31. Therefore we do not agree with the author when he states that Suess' suggestion that the gypsum beds (of Mesopotamia, Persia, etc.) represent the south-east extension of the Schlier (a special shallow water phase of the Burdigalian) cannot be maintained.

The structure of Mesopotamia is simple, and intimately connected with that of Persia. The important factor is a thrust from the north-east, which has caused rocks of all ages to be folded on an axis north-west-south-east. In Persia this thrust has caused tightly compressed and contorted folding, but in Mesopotamia the force seems to have spent itself with the result that more and more gentle folding is seen as one travels from east to west. The greatest period of folding took place in later Pliocene times, but we suspect that it had been going on along the same lines since Cretaceous times.

Chapter viii deals with economic geology. Plate viii gives all the recorded occurrences of minerals in the area covered by this book.

Mesopotamia is shown to be barren of minerals with the exception of petroleum. Coal is marked in several places, but an examination of the specimens from several of these localities indicates very strongly that the substance is an oil residue allied to "manjak". In Armenia a great variety of minerals occur, but inaccessibility would be a serious factor from a commercial point of view.

Chapter viii, part ii, the Persian-Mesopotamian Oilfields. This chapter will be read with great interest by oil technologists. As the oil is found for the most part in the gypsiferous series, the discussion of its age and origin is of great value.

The Geology of Mesopotamia and its Borderlands is concisely written, well illustrated with maps and sections, and provided with an excellent bibliography. In view of the prominence of Mesopotamia and Persia in the public eye, this publication is of great practical value.

A. H. NOBLE.

THE MINERAL INDUSTRY OF THE BRITISH EMPIRE AND FOREIGN COUNTRIES. Imperial Mineral Resources Bureau Digests : Antimony, pp. 34, 1s. net ; Cobalt, pp. 22, 9d. net ; Aluminium and Bauxite, pp. 35, 9d. net ; Zinc, pp. 112, 3s. 6d. net. Stationery Office, 1921.

THE general plan of this valuable series has been already described in a review of the first ten parts in the GEOLOGICAL MAGAZINE for February of the present year. The four further publications listed above are drawn up on similar lines, the chief difference being in the much larger amount of space allotted to zinc, this, of course, being properly commensurate with its greater technical and industrial importance. Any such publications at the present time naturally form somewhat depressing reading, owing to the stagnation prevailing in almost all the mineral and metallurgical industries. Besides their value as a record of present resources and a forecast of future possibilities, they will always be most useful as a summary compiled from reliable sources of the general trend of the mineral industries during the war period. The extensive bibliographies in each section will be greatly appreciated by all workers on economic mineralogy.

THE RADIOLARIAN CHERTS OF THE FRANCISCAN GROUP. By E. F. DAVIS. Univ. Calif. Publ. Bull. Dept. Geol., vol. xi, No. 3, 1918. pp. 235-432, 16 text-figs., 14 plates.

THIS monograph on the Franciscan Cherts naturally divides itself into three parts : a descriptive and comparative study of the cherts of the Franciscan and the allied Monterey Group ; a comparison with similar cherts in other regions, and finally a critical discussion of possible modes of origin.

There are two horizons of Franciscan chert, one 530 feet thick

and the other 900 feet. The cherts consist of iron-stained amorphous silica, in which are embedded the remains of radiolaria. These rarely form a large proportion of the chert. The amorphous silica is peculiar. It is hard enough to scratch quartz and contains much less water than opal. In the field these cherts are interbedded with thin siliceous shales, but the cherts make up by far the greater bulk of the rock. They appear to have a striking resemblance to the Culm Cherts of England, and differ both in mode of occurrence and petrographically from flint and many other occurrences of chert. The Franciscan Group has been invaded by basic intrusives, which have metamorphosed the cherts. In some cases the alteration results in a quartzite, but more peculiar changes are recorded such as the production of spherulitic and mammillated cherts, and occasionally, at the contact, of glaucophane schist.

Whilst the earlier and more descriptive parts of the paper are, perhaps necessarily, rather tedious, such a criticism does not apply to the concluding discussion of modes of origin. A comparison with radiolarian rocks of the West Indies shows that these cherts were not originally radiolarian oozes. Although the intercalation of these chert beds with sandstone indicates a shallow water origin, the author rejects the lagoon-phase theory of Dixon and Vaughan, largely because peculiar geological conditions are required of which there is no evidence, and because of the absence of calcareous remains. The enormous bulk of silica in these rocks is all out of proportion to the number of siliceous organisms present, and impossible to account for on the ground of precipitation from ordinary sea or river water. The general indications of igneous activity makes the author's supposition reasonable that submarine siliceous springs largely contributed the supply. It is further considered that this silica was precipitated together with terrigenous material, and that the rhythmic alternation was due to the segregation of the silica from the colloidal mass. The rhythmic bedding differs rather from the precipitation banding of Liesegang, on account of the continuous concentration of closely spaced bands, and also in the presence of transgressive bedding. This hypothesis is studied in a set of ingenious experiments on the rhythmic separation of a silica gel from intimate admixture with mud, and these deserve the close attention of all workers interested in segregation problems.

W. A. R.

THE FORAMINIFERA OF THE BONAVENTURE CHERTS OF GASPÉ.
By R. M. BAGG. *Bull. N. York State Mus.*, Nos. 219, 220.
Fifteenth Report of the Director, 1918. 8vo., 60 pp., 6 plates.
Albany, 1921.

THE careful examination of six thin rock sections of chert pebbles from the Bonaventure formation (Devono-Carboniferous) of the Gaspé Peninsula, Canada, by Dr. R. M. Bagg, has given

interesting results. These beds lie flat on vertical Devonian, Silurian, Ordovician, or Cambrian, and the included pebbles are recognizable fragments of the underlying rocks. Dr. Bagg considers the cherts to be Cambrian or Ordovician, and has identified seventeen genera and forty-five species of Foraminifera, many Sponges, some Radiolaria, Bryozoa, etc. The Foraminifera are uncrushed, present perfect outlines, and reveal many genera (as *Virgatina* and *Bolivina*) usually associated with more recent deposits. The paper is illustrated with four plates, and the carefully drawn figures of the sectioned specimens are placed side by side with the recent form. Altogether an important and interesting communication, involving a great deal of study and knowledge.

REPORTS AND PROCEEDINGS.

LIVERPOOL GEOLOGICAL SOCIETY.

12th April, 1921.—W. T. Walker, Esq., B.Sc., F.G.S., President, in the Chair.

The following paper was read: "On certain Mineral Deposits in Stratified Rocks, with special reference to the Carboniferous and Trias." By H. W. Greenwood, F.G.S.

The mineral deposits dealt with included the lead and zinc deposits of the Carboniferous limestones of Somerset, North Wales, Derbyshire, Northumberland, and Cumberland, the copper deposits of Alderley Edge, Cheshire, and of Ecton, and the hematite deposits of North and South Wales, Lancashire, and Cumberland, all of which were considered to possess common characteristics summarized as follows, viz. :—

(1) The deposits are all younger than the rocks in which they occur, they all show definite signs of having been deposited at a period later than the major earth-movements of the areas in which they are found, and also later than the major denudation of the particular districts.

(2) Their component minerals have all reached their present position by a process of solution and percolation, and have obviously been derived from above and not from below, in which they are in marked contrast to magmatic ore bodies.

(3) They generally take the form of filling of joints, cracks, faults, solution fissures, and are often metasomatic replacements.

A detailed description of the various deposits was given, and evidence adduced to prove that the lead and zinc ores were certainly of post-Triassic age in the Mendip area, and of much later date in the other areas. In practically every area they occur at altitudes over 500 feet above sea-level, i.e. in areas of comparatively high relief. The hematite deposits on the contrary occur at relatively low levels,

and almost always at less than 500 feet above sea-level, and it was suggested that they had been derived from formerly overlying Triassic rocks. For the Trias as laid down, it was considered that a content of $2\frac{1}{2}$ per cent of iron could not be regarded as an excessive estimate, which would be equivalent to 50,000 tons of hematite to a square mile of rock, 1 ft. thick, an amount quite adequate to account for the iron-ore deposits of the localities described.

INSTITUTION OF PETROLEUM TECHNOLOGISTS.

27th April, 1921.

“The Mackenzie Oilfield of Northern Canada.” By Dr. T. O. Bosworth, F.G.S.

A great expanse of Devonian rocks is exposed in the Mackenzie basin of the North-West Territory. It extends northward beyond the present railroads of Northern Alberta for more than a thousand miles to the Arctic coast. Since the exploration of the region by R. G. McConnell in 1887, who mapped the general boundary of the Devonian area, no further geological study was made until 1914. In that year Dr. Bosworth led a geological expedition to investigate the stratigraphy and structure of the Devonian rocks and to search for oil. Several prospective oilfields were outlined by this expedition, and sites for test wells were selected. At length, in 1919, drilling machinery was sent into the north, and in 1920 the No. 1 test well was drilled, with the result that oil in large quantity has been struck at a depth of 783 feet. This discovery well is the first well drilled in the North-West Territory. It is within 90 miles of the Arctic Circle and is the most northern oilwell in the world.

The author has divided the Devonian of this region into the following members :—

Camp Creek Series.

Clay shales and green oilsands, thickness 2,000 feet.

Fort Creek Shales.

Bituminous black shales, thickness 500–1,000 feet.

Beavertail Limestone.

Bituminous dark limestones, thickness 350 feet.

Rampart Limestone.

Massive fossiliferous grey limestone, thickness 100–200 feet.

Hare River Shales.

Calcareous clay shale, thickness 300 feet.

Barren Series.

Brecciated dolomites and massive grey limestone, probably only in part Devonian, thickness 2,000 feet.

The Devonian strata in the Mackenzie Oilfield have been thrown into a series of bold asymmetrical folds. Four main anticlines were determined, parallel to one another, and about 7 miles apart. Their direction, where the river crosses them (80 miles beyond Fort Norman), is slightly north of east ; but on the east side of the

river they bend round to an E.S.E. course, which is maintained for 75 miles, and probably is their main direction. Wherever the upward pitching of the axes brings the limestone members up above the general level of the land, the denudation has developed out these limestone arches as conspicuous anticlinal hills. Thus the main anticlines are seen as chains of more or less continuous limestone hills, exceeding 1,000 feet in height.

The principal surface showings of oil arise from the Camp Creek Series. In the well oil was found throughout these beds and also in the Fort Creek Shales, in which measures the present large flow of oil has been encountered. The oil is of high quality, having specific gravity .845 and containing 22.5 per cent of petrol. In view of the thickness and extent of the petroliferous formations, the favourable structural conditions, and the copious showings of oil, it is thought that a great oilfield region has been discovered.

GEOLOGISTS' ASSOCIATION.

Friday, 6th May, 1921.

"The Geological History of the Pewsey Vale." By W. D. Varney, B.Sc.

General description of the Geology and surface features of the country surrounding the Pewsey Vale. Folding of the Pewsey Anticline, in Cretaceous, Miocene, and Pliocene times—description of the drainage system so initiated. Plateau Gravels near Bradford Gorge of Bristol Avon—evidence of a river flowing eastwards. Relationship of such a river to the Pewsey Vale and the present Salisbury Avon. Reversal of the drainage by the River Severn, and the development of the Bristol Avon. Drainage still being modified by the Bristol Avon at the western end of the Pewsey Vale, illustrating how the Bradford Gorge was formed. Comparison with the Kennet and other rivers. The last stages in the shaping of the Pewsey Vale, down to recent times. Recession of the Chalk Escarpment in Wiltshire. Maps showing changes in drainage since Pliocene times.

"On a Superficial Deposit at St. Andrew's, Guernsey." (1) A description of the Section. By B. G. Chilcott, F.G.S., and L. Richardson, F.R.S.E., F.G.S. (2) Petrology of samples of Brick-earth, etc., from the locality. By P. G. H. Boswell, O.B.E., D.Sc., F.G.S.

EDITOR'S NOTE.—Owing to the large number of important original papers now on hand, it has been found impossible to spare even one page for Editorial Notes. For the same reason the number of pages allotted to reviews and reports is somewhat smaller than usual.

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- SPURR (J. E.), Editor. *Political and Commercial Geology and the World's Mineral Resources. A series of studies by specialists.* New York, 1920. pp. ix, 562. 8vo. Illustrated. Cloth. £1 10s.
- TEALL (J. J. HARRIS), M.A., F.G.S. *British Petrography: with special reference to the Igneous Rocks.* With 47 plates. Royal 8vo. Cloth. £3 3s. net.
- VAN DEN BROECK (E.), MARTEL (E. A.), AND RAHIR (EDM.). *Les Cavernes et les Rivières souterraines de la Belgique.* Bruxelles, 1910. 2 vols. 8vo. With 26 plates and text illustrations. Boards. £1 10s.
- WOODS (H.). *Palæontology: Invertebrate.* Fifth edition. 8vo. Cloth. Cambridge, 1919. 12s. 6d.

JUST PUBLISHED.

Catalogue of the Fossil Bryozoa (Polyzoa) in the Department of Geology, British Museum (Natural History). *The Cretaceous Bryozoa* (Polyzoa). Volume III. The Cribrimorphs, Part I, by W. D. LANG, Sc.D. pp. 269, 8 plates, and 115 text-figures. With general index, index to systematic names of Polyzoa and explanation of Plates. 8vo. Cloth. £1 10s.

The Jurassic Bryozoa, by J. W. GREGORY, D.Sc. pp. [viii] 239, 22 woodcuts, and 11 plates. 8vo. Cloth. 1896. 10s.

The Cretaceous Bryozoa, by J. W. GREGORY, D.Sc. Vol. i, pp. xiv, 457, 64 woodcuts, and 17 plates. 8vo. Cloth. 1899. 16s.

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THE GEOLOGIST.

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JULY, 1921.

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THE SECRETARY OF STATE FOR INDIA proposes to make **four Appointments** to the **Geological Survey of India** in August next. Preference will be given to candidates who have served in His Majesty's Forces during the war. Besides a good general education, a sound education in Geology is essential; a University degree and a knowledge of French or German will be regarded as important qualifications. Candidates should not be more than 25 years of age, but this rule may be relaxed in exceptional cases.

Detailed regulations and forms of application can be obtained from the SECRETARY, Industries and Overseas Department, India Office, London, S.W.

Applications for appointment must be received not later than 1st August.

THE GEOLOGICAL MAGAZINE

VOLUME LVIII.

No. VII.—JULY, 1921.

EDITORIAL NOTES.

THE Mines Department announces the formation of an Advisory Committee to assist the Secretary for Mines in matters relating to the Metalliferous Mining Industry. Never was the mining of metalliferous ores in this country in a more parlous condition, for, with the exception of iron ore and ironstone mining and quarrying, practically all the metal mines of the country are shut down, for the very good reason that the cost of production of the dressed minerals is higher than the price at which they can be sold. The high price of production is to be ascribed partly to the increased cost of labour, partly to the high price of materials; while the low price offered for the products is due partly to the low level at which the metals stand in the markets of the world (they are down in some cases nearly to pre-war level), and partly to the high returning charges of the smelters, whose costs have been heavily increased both by the high price of labour and the excessive cost of fuel. Mr. Bridgeman is to be congratulated on being able to get together such a representative body to advise the Mines Department. Its constitution is as follows:—

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Professor Henry Louis, D.Sc.	
Dr. James Malcolm Maclaren	
	{ Economic Geologists.

Mr. J. J. Burton	{	Representing the Iron and Steel Industry.
Sir Kenneth Weldon Goadby, K.B.E.		Representing Medical Science.

Mr. F. C. Starling, of the Mines Department, will act as Secretary to the Committee.

The Chairman, Sir Cecil Budd, is well known as the Chairman of the British Metal Corporation and of the London Metal Exchange, and as an authority on the non-ferrous metals generally. Of the representatives of owners of ironstone mines and quarries General Jackson is interested in the iron mines of Cumberland, Mr. Myles Kennedy in those of Lancashire, and Mr. Claud Pease in those of the Cleveland district; while Mr. Lloyd owns ironstone quarries in Northamptonshire, Mr. Thomas represents the owners of tin mines and Mr. Anthony Wilson the owners of lead and zinc mines. Of the representatives of the workers Mr. Harry Dack represents the Cleveland miners, Mr. Gavan Duffy those of Cumberland, Mr. Lewney those of Lancashire, Mr. Sherwood the ironstone quarrymen, Mr. Harris the tin miners, and Mr. Wignall the lead and zinc miners. Economic Geology is well represented on the Committee, Mr. Hall being especially acquainted with the geology of the lead and zinc mines of Shropshire, Dr. Maclaren with the tin mines of Cornwall, and Professor Louis with the iron mines; Dr. Hatch, although he appears among the mining engineers, is also not unknown as an economic geologist. The other mining engineers are Mr. Merricks and Mr. Falcon; while Mr. Harbord represents metallurgy. Mr. Burton, of Middlesbrough, will advise on the iron and steel industry generally, and Sir Kenneth Goadby on the medical aspects of mining. The Committee will hold its first meeting on 5th July.

* * * * *

THE Imperial Mineral Resources Bureau continues to issue at intervals its "monographs", or, to give them their proper title, "Digests of statistical and technical information relative to the production and consumption of the metals and useful minerals." Up to the present fifteen have appeared, namely, those on aluminium and bauxite, antimony, arsenic, asbestos, bismuth, borates, chrome ore and chromium, cobalt, felspar, Fuller's Earth, magnesite, manganese, monazite, nitrates, and zinc. One on tungsten will be published shortly and others are in an advanced state of preparation. These include some important monographs, for instance, those dealing with iron, coal, and copper. That on iron will be entitled "The Iron Ore Resources of the World", and will be practically on the lines of, but bringing up to date, the report of the Geological Congress which met at Stockholm in 1910. Special funds for the purpose have been contributed by the National Federation of Iron and Steel Manufacturers.

* * * * *

MEANTIME the figures for the world's production of minerals for the years 1914-18 have for the bulk of the minerals not yet been published, and similar figures for the years 1919 and 1920 are becoming due. These statistics used to be published by the Home Office, in Part IV of the Report of the Chief Inspector of Mines. During the war their publication was suspended, and on the formation of the Bureau the duty of compiling and publishing them was delegated to the new body. We cannot help thinking that it would have been wiser to have got out as rapidly as possible these vital statistics, and to have left the less important, but interesting, letterpress of the monographs for a more leisurely procedure. Mining engineers all the world over would have welcomed the publication of the production figures, and would have been content to wait until the staff of the Bureau should have had time to cope with the compilation of the monographs.

* * * * *

THE fourth report of the Conjoint Board of Scientific Societies shows that the Board has received evidence that scientific investigation is being seriously hampered by the heavy cost involved in the publication of results. An exceptional number of papers are being communicated to the Scientific Societies, including many held up during the war, while the resources of the Societies, which have not increased, are insufficient at present prices to publish even the normal pre-war number. The country is thus in danger of being seriously handicapped at a time when the rehabilitation of industry is in most serious need of scientific assistance. Much of the report is occupied with a short abstract of the third report of the committee on the water power of the Empire. It is shown that too little is being done to ascertain the total resources, or to secure uniformity in investigation and record. It is urged that steps should be taken to convene an Imperial Water Power Conference in London, at which the various Dominions and Dependencies of the Empire should be represented. The outcome of such a conference might well be the creation of an Imperial Water Power Board, with extensive powers to carry out a comprehensive policy for stimulating, co-ordinating, and, where necessary, assisting development throughout the Empire. The Board has also dealt with questions relating to the formation of National Research Committees, in connexion with the International Research Council, formed in 1919, with the collection of scientific data in the former German colonies, and with instruction in technical optics. The research on glues and other adhesives initiated by the Board as a war measure, at the instance of the Air Ministry, has now been taken over by the Department of Scientific and Industrial Research.

ORIGINAL ARTICLES.

An Eminent Living American Geologist and Palaeontologist.—Professor John M. Clarke,

LL.D., D.Sc., For. Corr. Geol. Soc. Lond., Director of the New York State Museum, Albany (New York), U.S.A.

WITH A PORTRAIT (PLATE V).

THE State of New York has long been famous as the centre from which radiated out geological life and energy to the early explorers, whose followers are now to be found spread over the vast States of America. The names of Emmons, Silliman, Dana, and Hall, and a host of other great geologists, may be cited, whose records will never die, and whose work is now being carried on by their living representatives. Such a surviving successor of James Hall now worthily fills his chair at the Albany Museum.

Professor John M. Clarke was born in 1857 in the Puritan village of Canandaigua, in the "Finger Lakes Region" of Western New York State, amid the rich Devonian fossiliferous rocks. Mr. Clarke's boyish desires naturally turned to the study of his native rocks and fossils. His home life was simple and well influenced, his father being for nearly two generations the principal of the Academy, and both father and mother were of the Puritan stock which came out from Old England to Massachusetts in the first half of the seventeenth century. After school and college days, Mr. Clarke became a teacher of geology, first at Amherst College, from which he had graduated; afterwards at Smith College, and this active interest in imparting knowledge he has retained to this day as professor of geology in the Rensselaer Polytechnic Institute, with which he has been associated for more than twenty-five years, in succession to Amos Eaton, Ebenezer Emmons, and James Hall. As a mature student of geological science, Mr. Clarke spent three years at Göttingen, and on his return from Europe he joined on 2nd January, 1886, the staff of Professor James Hall, the distinguished palaeontologist and geologist at Albany, where he has remained ever since, in the geological service of the State of New York.

At the time of Mr. Clarke's advent at Albany, James Hall was 75 years old, and while his vigor and enthusiasms were unimpaired and his devotion to his great work, the *Palaeontology of New York*, unstinted, the extensive researches necessary to carry this work forward naturally fell on younger men. Hall was then in the midst of his greatest productiveness, but his assistant, the late Charles E. Beecher, was leaving and soon the labour of the preparation of these great volumes in all their extensive details of research, drawing, lithography, and printing fell to Clarke, his new assistant. The volume on the Devonian Trilobites and other Crustacea (vol. vii), and the two volumes on the Genera of the Palaeozoic Brachiopoda (vols. viii, parts i and ii), were prepared by Mr. Clarke, the latter with the help of illuminating suggestions from Charles Schuchert. But all this work of the assistant, though usually not seen by Professor Hall until in type, was carefully read, annotated, and generously accepted by him.



John M. Clarke

For twelve years this intimate association with Hall continued—until his death in 1898 at the age of 87; and the longer it grew the more the various responsibilities of the work of the State Geological Survey fell upon the shoulders of the younger man. Though Hall believed that the *Palæontology of New York* would die with him, he taught his associate to plan his work on broad and comprehensive lines, a lesson which was interestingly emphasized by the publication a few months after his death of the most impressive of all his volumes, the great monograph of the Devonian Hexactinellid Sponges, which appeared jointly over the names of the master and his assistant. On the death of Hall, Mr. Clarke was made State Palæontologist, and six years later, under a reorganization of the State Education Department and the University of the State of New York, he was installed as State Geologist and Palæontologist, which positions involved also the Directorship of the State Museum and the Department of Science of the University. These responsibilities have continued since 1904. During this period the study of the older rocks of the State of New York and the exposition of its extraordinary postglacial history have gone on with activity and the necessary publications, with the help of a strong body of skilled men, have grown to the number of several hundred. New York is a State covering 4,500 square miles, and its rock geology extends from the Precambrian complex of the Adirondack Mountains and the lower Hudson Valley to a fringe of Cretaceous and Tertiary along the marine shore of Long Island, all between being the Palæozoic plateau in which the faunas of the Cambrian, Ordovician, Silurian, and Devonian are extraordinarily rich and well preserved. Nearly one-half the area of the State is built on the Devonian and this is the formation and fauna that have called forth Mr. Clarke's special labours. As a general consequence of the progress of the survey work, the great geological map of New York State on a scale of one mile to the inch, has been somewhat more than half completed in careful detail.

Mr. Clarke's active interest in the study of the Palæozoic rocks has extended beyond the confines of his State, and he has published quarto volumes on the Devonian geology and palæontology of the Gaspé Peninsula of Lower Quebec, New Brunswick, and Maine. Invited by the late Orville A. Derby, F.G.S., to participate in the geological work of Brazil, he has prepared papers on the Palæozoic faunas of the Amazonas and a quarto memoir, the only one thus far issued by the present Federal Survey of Brazil, on the Devonian of the State of Sao Paulo.

Among the requirements of administrative work, the creation of a new State Museum has been of foremost importance. This is a purely scientific museum, devoted to the exemplification of the Natural History of New York State only, and is very effective in the character of its exhibits, but the installation of this extensive museum in its new quarters in the Education Building has not interfered with the progress of scientific research. Among the lines

of investigation that he has pursued for some years is the geological beginnings of symbiosis and parasitism, and he has now in press a work on the Origin of Dependent Life and the Significance of Disease, a treatise based essentially on palæontological data.

Mr. Clarke has been president of the Geological Society of America and of the Palæontological Society. He was Chairman of the War Committee on Geology under the first organization of the National Research Council, and is Chairman of the Geology and Palæontology Section of the National Academy of Sciences. He has received the degree of LL.D. from Amherst and Johns Hopkins, and D.Sc. from Princeton, Chicago, and Colgate. He has also received the award of the Hayden Gold Medal of the Philadelphia Academy of Natural Sciences and the Spindiaroff prize of the International Geological Congress. Outside of his own proper branches of science he has concerned himself actively in the conservation of the native birds, and the native flora, and for aid rendered in protection of the wild-fowl colonies of the Gulf of St. Lawrence has received the rare gold medal of the Wild Life Permanent Protection Fund. A township in Gaspé, where he has spent many seasons of scientific work, has been named for him by the Quebec Board of Geographic Names.

Mr. Clarke is a member and officer in a good many societies, scientific and historical, and among others is a corresponding member of the Geological Society of London. He has been for several years President of the Albany Burns Club, one of the oldest literary clubs in America, and is now President of the venerable Albany Institute and Historical and Art Society (founded 1791).

Space will not permit us to add a list of titles of all Professor J. M. Clarke's publications, but we desire to refer to some of the more important:—

1. *Palæontology of New York*, vol. vii (with James Hall): "Trilobites and other Crustacea of the Devonian of New York." 1888.
2. *Palæontology of New York*, vol. viii, pts. i, ii (with James Hall): "Introduction to the study of the genera of Palæozoic Brachiopoda." 1894.
3. *Handbook of the Brachiopoda* (with J. Hall), 2 vols. 1894. 8vo.
4. *The Palæozoic Reticulate Sponges—constituting the family Dictyospongidae* (with J. Hall). 1898.

[Note.—Nos. 1–4, these were all written by J. M. Clarke.]

5. *The "Naples" (Upper Devonian) Fauna in Western New York*. 1904.
6. *Early Devonian of New York and Eastern North America*, 2 vols. 1909.
7. *Fossils Devonianes du Parana*. 1903.
8. "*Guelph*" *Formation and Fauna of New York State* (with R. Ruedemann). 1903.
9. In 1912 Clarke, assisted by Dr. Rudolph Ruedemann, issued two grand volumes from the State Museum, Albany, entitled Memoir 14, *The Eurypterida of New York* (one volume of text pp. 440 quarto, with 121 text-figures, and one volume of 88 plates and pp. 441–628 of explanation of plates (with a full index). It is delightful to find in these volumes such a grand collection of new material relating to the American Merostomata all carefully studied and described, together with copious foreign literature relating to the order.¹—H.W.

(Except No. 3 all the quarto publications.)

¹ See GEOL. MAG., 1913, pp. 293–300.

Note on the Sequence across Central Spitsbergen from Advent Bay to Agardhs Bay.

By J. W. GREGORY, F.R.S.

THE collections described by Mr. Spath were made during Sir Martin Conway's Expedition across Spitsbergen in 1896, and include also those then collected by Professor Garwood and presented by him to the British Museum of Natural History.

The Mesozoic fossils were mainly obtained between Ice Fjord and Agardhs Bay, and especially along the Sassendal where the Triassic beds are well developed. The general relations are clearly shown in the northern side of that valley; the block at the western end is composed of Carboniferous rocks, which dip gently eastward and disappear under the black shales and flags of the Trias.

Our route lay along the southern side of the Sassendal, where at the western end, between Waterfall Camp and the shore of Ice Fjord, a conspicuous platform of Carboniferous rocks projects from the base of the escarpment. The Carboniferous rocks are represented by Productus Limestone in the two cliffs along the shore; and further west, near Waterfall Camp, by cherts and coral limestone.

The Carboniferous beds are covered by the Trias with a slight unconformity between them; this was recognized by direct measurement at the angle between Sassendal and Fulmar Valley, where the Carboniferous beds dip 4° to south-south-west, and the Trias 2° to south-east. The general Triassic sequence is well exposed along the escarpment on the southern side of the valley, as in Sticky Keep to the west, and in the Trident to the east of the valley leading up to Brent Pass. The general succession in descending order may be summarized as follows:—

	<i>Approximate thickness in feet.</i>
SECTION I.	
G. Plateau Flags: yellowish, unfossiliferous shaly flags	400
F. Upper Nodule bed.	
E. Oozy Mound beds: thin dark grey to black shales with phosphatic nodules. Fossils in three seams.	400
(3) Upper seam—Belemnites.	
(2) Middle seam— <i>Daonella</i> , etc.	
(1) Lower seam—Nos. 31–5.	
These shales pass down to shaly flags with the ribbed <i>Pseudomonotis</i> .	
D. Escarpment Shales.	
(4) A 3 in. Limestone.	200
(3) Thin paper shales with many Ammonites, reptilian bones, etc.	
(2) Middle Nodule bed.	
(1) Earthy Limestone.	
C. 2. Black Shales and yellow flags; with fish, mollusca, etc., and many <i>Posidonomya</i> : (Professor Garwood found a reptile rib in the Trident)	600
C. 1. Lowest Nodule bed.	
B. Unfossiliferous black shales: few exposures.	500
A. Carboniferous Limestone.	

The succession above the Trias in this part of Spitsbergen was seen to the west of Lower Sassendal during an ascent, in company with Sir Martin Conway, of Mount Lusitania. The sequence is as follows, in descending order :—

SECTION II.

Jurassic.

(g) Grey to greenish flags with beds showing cauda-galli and cone-in-cone structures.

(f) Quartzose grit.

(e) Pebble bed and conglomerate. Snow covered.

Middle Trias.

(d) Black shales and upper nodule bed. Snow covered.

(c) Buff to greenish flags; no fossils seen.

(b) Escarpment shales and flags.

(a) Middle Nodule bed.

Carboniferous.

Further east than the Mount Lusitania section an ascent from the de Geer Valley crossed the same general sequence.

- Jurassic { (h) Grits capping the plateau.
(g) Flags with cauda-galli structure.
(f) Shales with intersecting and radial tracks (so-called Starfish bed).
(e) Hyperite sill which alters and bleaches the shales above and below.
- Middle { (d) Upper Nodule bed in black shales.
(b-c) Flags.
- Trias { (a) Middle Nodule bed.

The intrusive character of the hyperite, and excellent sections of trough faulting are shown in coast sections between the de Geer Valley and Advent Bay.

From the eastern end of the Sassendal the Fulmar Valley affords a good section from the Carboniferous to the Jurassic; and as the beds dip southward both the Carboniferous and Trias disappear, and the Jurassic beds form the chief rock exposures on both sides of the Upper Fulmar valley.

The character of the Jurassic and Cretaceous beds was best seen south of Advent Vale, in the scarps from Bunting Bluff to the Booming Glacier.

The succession may be thus summarized :—

		<i>feet.</i>
Middle Cretaceous	{ Brown shales.	500
	{ Quartzitic flags with few pebbles.	
	{ Conglomerate with pebbles of quartz, chert, granite, etc.	
Jurassic	{ Bunting Bluff Limestone.	400
	{ Ironstone nodules: fossiliferous.	
	{ Rotten flags.	
	{ Shales with plant remains; few exposures.	
		1000

The intrusive nature of the hyperite is well shown in the north-east wall of the Fulmar Valley; a sill oscillates slightly in level for some distance and then cuts steeply across the strata, becoming thinner in its ascent.

On Ammonites from Spitsbergen.

By L. F. SPATH, M.Sc., F.G.S.

OF the rich collections of fossils made by Professors J. W. Gregory and E. J. Garwood, as members of Sir Martin Conway's expedition to Spitsbergen in 1896, only a few Labyrinthodont remains, so far, have been described¹; but through the kind offices of Dr. A. Smith Woodward, the writer some time ago was entrusted with the naming of the Cephalopoda in those collections. The Ammonites are of the greatest interest, both from a palæontological and a stratigraphical point of view; and in view of the impossibility of publishing, in the near future, a full description of the fauna, with the necessary number of plates, it is intended to give a short preliminary account of these Cephalopoda. It is matter for regret that other groups of invertebrate fossils, such as the Triassic Pelecypoda, or the Upper Jurassic Aucellids, could not be dealt with, and their detailed study, probably, would yield important results. Spitsbergen Vertebrata, on the other hand, always have received considerable attention.²

The collections include 325 Ammonites from the Lower and Middle Trias, but there are no Upper Trias forms, such as the Carnian *Nathorstites* and *Dawsonites*, which are common enough on Bear Island, and which also have been recorded from Spitsbergen.³ Triassic Nautiloidea are only represented by three examples of *Orthoceras*, one from the Lower Triassic "Nodule bed", another (without label) associated with an indistinct impression of an *Arctoceras*?, and the third from a black limestone that may be of Middle Triassic age.⁴

Two fragmentary examples of *Atractites* sp. ? probably are the "*Belemnites*", mentioned in bed E₃ of Professor Gregory's section I, but there was no label with these specimens, though they were associated with Ammonites from Trident, Sassendal.

Thirty-one Ammonites are of Upper Jurassic (Kimmeridgian to Purbeckian) age, and a few fragments of *Belemnites* are referred to the same age. Finally, there are nine Cretaceous Ammonites, two of which can more or less definitely be dated as

¹ A. Smith Woodward, "On Two New Labyrinthodont Skulls of the genera *Capitosaurus* and *Aphaneramma*": *Proc. Zool. Soc.*, vol. ii, 1904.

² For bibliographies see e.g. C. Wiman, *Bull. Geol. Inst. Univ. Upsala*, vol. xvi, 1919, p. 85, and E. Andersson Stensjö, *ib.*, p. 80.

³ Wittenburg, P. v., "Üb. einige Trias. Fossil. v. Spitzbergen": *Trav. Mus. Géol. Pierre le Grand*, vol. iv, 1910, p. 38. The Upper Trias seems to be developed chiefly on the eastern side of Spitsbergen. It may be mentioned in this connexion that a collection of fossils, made this summer (1920) by Mr. W. J. Reynolds, and lately presented to the British Museum, includes a number of Middle Triassic Ammonites from Sassen Bay and Bell Sound, Spitsbergen; but both Upper and Lower Trias are unrepresented by Ammonites in this collection.

⁴ A *Grypoceras* ? *nordenskjöldi*, Lindström sp., from "West of Fortress" near Cape Staratshin, West of Green Harbour, is in the Reynolds Collection.

Valanginian, whereas the others are doubtfully referred to the Albian. The stratigraphical information supplied unfortunately consists only of the data here copied from the labels attached to the specimens. The localities are mentioned in Sir Martin Conway's well-known book, *The First Crossing of Spitsbergen*,¹ and mostly recorded on the map appended to that work and to his paper in the *Geographical Journal*.² Since the mineral wealth of Spitsbergen is now attracting considerable attention,³ it may be hoped that additional material and more extensive stratigraphical observations will soon be available.

After this paper was completed, Professor J. W. Gregory kindly sent the writer his "Note on the Sequence across Central Spitsbergen, from Advent Bay to Agardhs Bay", published herewith, so that it has been possible to insert some references to the beds mentioned in Professor Gregory's sections. But in view of the fact that some of the specimens were collected from loose blocks, that there are differences in the nomenclature that the writer is unable to settle, also that most of the specimens collected by Professor E. J. Garwood, especially the Jurassic ones, come from other localities, a complete list of the Ammonites, arranged according to the sections mentioned by Professor Gregory, cannot be given. The table at the end of the chapter on the Triassic portion of the Ammonite fauna, however, is an attempt at a correlation for that period.

I. TRIASSIC.

The great majority of Ammonites belong to the Lower Trias, and can be referred to the following genera:—

<i>Arctoceras</i> ⁴	<i>Prionites</i>
<i>Olenekites</i> ?	<i>Anasibirites</i>
<i>Flemingites</i> ?	<i>Keyserlingites</i>
<i>Gyronites</i> ?	Gen. nov. (<i>Danubites</i> ?,
<i>Goniodiscus</i>	<i>Xenodiscus</i> ?)
<i>Tellerites</i>	<i>Prospiringites</i> ?

The last two are represented by 100 and 66 specimens respectively; *Arctoceras* by 82. The latter genus includes, in addition to a number of less definitely identifiable species, seven forms described by

¹ 1897, J. M. Dent & Co., London.

² Vol. ix, No. 4, April, 1897, pp. 353–68, map, p. 472.

³ See "Recent Developments in Spitsbergen", by Dr. R. N. Rudmose Brown: *Scott. Geogr. Mag.*, vol. xxxvi, April, 1920, No. 2, pp. 111–16; also the same author's "The Coal-fields of Spitsbergen": *Nature*, October 9, 1919. The summer population of Spitsbergen (1919) is estimated at 1,000.

⁴ Hyatt, 1900 (in Zittel's *Text-book of Palæontology*, vol. i, p. 559), non *Arctoceras*, J. Böhm, 1899 ("Üb. Triad. Foss. v. d. Bären-Insel": *Zeit. Deutsch. Geol. Ges.*, vol. li, p. 326). In 1904 J. Böhm ("Üb. d. Obertriad. Fauna d. Bären-Insel": *Kon. Svensk. Vet.-Akad. Handl.*, vol. xxxvii, No. 3, 1903, p. 61) withdrew his *Arctoceras* in favour of Hyatt's term, and replaced it by another generic name for his Carnian group.

Mojsisovics,¹ namely *Arctoceras polare* (Mojs.), *A. simplex* (Mojs.), *A. whitei* (Mojs.), *A. blomstrandii* (Lindström), *A. lindströmi* (Mojs.)², *A. öbergi* (Mojs.), *A.?* *costatum* (Öberg). A number of small specimens, more evolute than the large examples, have lateral folds, or almost a spiniplicate ornament; but they occur with the young of undoubted *Arctoceras*, and, apparently, are connected with these by transitional forms. This may only be a case of convergence, for it is improbable that a spiniplicate development would give rise to forms that acquire costation on the outer whorl, as does *Arctoceras*. Only the smooth and more involute young, therefore, are considered to belong to *Arctoceras*. The others are like the young of "*Ceratites*" *decipiens* Mojsisovics, and of *Olenekites*, e.g. *O. sigmatoides*, Mojsisovics sp. The latter also resemble the young of forms referred to below as gen. nov. (*Danubites*?, *Xenodiscus*?) and Mojsisovics³ derives *Danubites* from *Olenekites*. The small forms, here compared with *Olenekites*, however, have a smooth ventral area, whereas in the gen. nov. there are constrictions across the venter, apparently arising from a spiniplicate ornament. It is impossible to say at present whether *Arctoceras* should be attached to *Dinarites* (in Mojsisovics), to *Olenekites* and *Keyserlingites* (in Hyatt), to *Flemingites* (in Philippi), or to *Meekoceras* (in Stolley).

The writer may add that a true spiniplicate *Olenekites* in the British Museum is distinguished from the small forms here discussed by its square saddles, characteristic for *Dinaritidæ*.

Four specimens consist of umbilical impressions of very large shells, probably *A. lindströmi*, Mojsisovics sp.; their matrix indicates the *Posidonomya* shales. Fifteen examples are merely impressions in more or less weathered slabs of rock. But, whereas the well-preserved specimens and the umbilical casts above referred to clearly come from the *Posidonomya* shales⁴ and generally are associated with numerous examples of *Posidonomya mimer* Öberg, these impressions are preserved in a very fine-grained black limestone, weathering yellow, and including (besides? *Hærnesia*) large smooth *Pseudomonotis* of the type of *P. (Claraia) decidens* (Bittner)⁵

¹ "Arktische Triasfaunen": *Mém. Acad. Imp. Sci. St. Pétersbourg*, ser. VII, vol. xxxiii, No. 6, 1886, pp. 29–38.

² Non "*Arctoceras*" *lindströmi*. J. Böhm in J. G. Andersson ("Üb. d. Stratigr. und Tektonik d. Bären-Insel": *Bull. Geol. Inst. Univ. Upsala*, vol. iv, 1899, pt. ii, No. 8 (1900), p. 265), a *Nathorstites*, that has nothing to do with the Lower Triassic *Arctoceras lindströmi* (Mojsisovics).

³ *Geb. u. Hallstatt*, Supplement, 1902, p. 329.

⁴ Or rather from limestone-nodules in the bituminous, marly shales, mostly wrongly referred to in literature as "*Posidonomya Kalk*", as has been pointed out by Professor Wiman ("Ein paar Labyrinthodontenreste a. d. Trias Spitzbergens": *Bull. Geol. Inst. Univ. Upsala*, vol. ix, (1908–9), 1910, p. 34). Most of the specimens are from "Nodule Bed, Base of Trident, Sassendal"; three examples only came from "lowest line of nodules" or "Lowest Limestone" on Mt. Marmier.

⁵ "Trias Brach. & Lamell.": *Mem. Geol. Surv. India, Pal. Indica*, ser. xv, *Himal. Foss.*, vol. iii, pt. ii, 1899, pl. i, fig. 24.

or of *P. (Claraia) aurita* (Hauer) in Diener.¹ These slabs are labelled "Lower Lamellibranch zone", Trident, but a few are from Sticky Keep, and there called "Upper Flags" (= Calcareous Flags; Bed above nodules?). The presence of iron-pyrites in the latter, however, is reminiscent of the calcareous *Arctoceras* nodules in the *Posidonomya* shales, and the rock is hard, whereas the somewhat similarly weathering examples from the "Upper Lamellibranch zone", with a very large *Pseudomonotis (Eumicrotis)*, generally have a more earthy, brownish appearance. One *Arctoceras* impression, merely labelled "Sassendal", may have come from this higher zone, but it is for future workers to investigate the range of *Arctoceras* in the shales and flags above the "Nodule bed".

A specimen of *Arctoceras blomstrandii* (Lindström) was attached to the umbilical impression of a very large shell, characterized by strong spiral ornament, on account of which the specimen is doubtfully referred to *Flemingites*. The longitudinal striation in this genus, however, is considerably finer than it is in the Spitsbergen example; and the writer at one time was inclined to compare this specimen with certain *Phloioceras* and other *Nautiloidea*. It seems most probable, however, that the example is a *Flemingites*, though spiral striation is also indicated in certain *Arctoceras*.² Another specimen of *Arctoceras* and numerous *Posidonomya mimer* are to be observed in the same specimen.

Two of the specimens referred to *Goniodiscus* are closely comparable with *Meekoceras gracilitatis* White,³ but the periphery is slightly broader. Young examples of the same form, however, have the costation of *Anasibirites*, and are so nearly related to the forms here referred to that genus, to *Prionites* and to *Tellerites*, that the resemblance to the genus *Meekoceras* (with perfectly smooth inner whorls) can only be a case of convergence. The suture-line of this new species of *Goniodiscus* agrees with that of *G. typus* Waagen,⁴ but the external saddle is a little wider in the Spitsbergen form. The latter also has a narrower and more sharply defined periphery.

Another new species of *Goniodiscus* has coarse pleats at the middle of the side, near the end of the shell, and thus is transitional to

¹ "Triassic Faunæ of Kashmir": *Mem. Geol. Surv. India, Pal. Indica*, n.s., vol. v, Mem. No. 1, 1913, pl. v, fig. 9.

² E.g. *A. öbergi* (Mojsisovics), loc. cit., p. 33, pl. viii, fig. 3. *Ceratites concentricus* Öberg ("Om Trias-Först. fr. Spitsbergen": *K. Svenska Vet. Akad. Handl.*, vol. xiv, No. 14, 1877, p. 15, pl. ii, fig. 12) has concentric markings, but Mojsisovics (loc. cit., p. 8), who examined the type, states that they are the result of crushing. To judge by a number of specimens in the Reynolds Collection, this form is a crushed *Ptychites* of the *Daonella* Beds.

³ In Hyatt & Smith, "The Triassic Ceph. Gen. of America": Prof. Paper No. 40, U.S. Geol. Surv., 1905, p. 143, pl. xii, figs. 7-9. Dr. C. T. Trechmann lately presented to the British Museum (Nat. Hist.) a very fine series of Triassic Ammonites from California, Nevada, and Idaho, U.S.A., including many topo-types of Hyatt & Smith's species.

⁴ "Salt Range Fossils: II. Fossils from the Ceratite Formation": *Mem. Geol. Surv. India, Pal. Indica*, ser. XIII, 1895, p. 128, pl. ix, figs. 7-10.

Prionites. A third form, at last, has these *Prionites*-folds very close, resembling in shape *Anasibirites hircinus* Waagen sp.,¹ but with the costæ pronounced only at the middle of the side, not near the periphery. The cross-sections of the last two forms approach to that of *Prionites tuberculatus* Waagen.²

A new species of *Prionites* is like the above in the character of the inner whorls. These somewhat resemble *Meekoceras sibiricum* Mojsisovics,³ but are more evolute, i.e. more like *M.* sp. ind. aff. *jolinkense* Krafft in Diener.⁴ On the other hand, the outer whorl agrees with that of the example of *Prionites tuberculatus* (Waagen), figured by Frech.⁵ The periphery, however, still suggests the *Goniodiscus-Anasibirites* stock; and since Waagen's type of *Prionites* is a much earlier form, it is quite possible that the forms of the *Stephanites*-zone do not belong to this genus. A large but fragmentary specimen of a *Prionites* sp. nov. aff. *tuberculatus* Waagen, has a more rounded outer whorl that strikingly suggests a transition to *Keyserlingites*.

A small specimen, probably belonging to a new form of *Tellerites*, but slightly malformed and not showing the suture-line, has the sigmoidal ornament of *T. furcatus* (Öberg), but the deeply channelled periphery of *Hedenstræmia* already at the diameter of Mojsisovics' small specimen,⁶ which latter, then, is still rounded. This ammonite, also, cannot be separated from the other "*Meekoceras*"-like forms here discussed, and certainly has nothing to do with the Middle Triassic *Norites*, with which *Tellerites* has been associated by Mojsisovics and Haug.

The genus *Anasibirites* is represented by thirteen examples from the Nodule Bed of the Trident, Sassendal, including one curious new form, transitional to *Goniodiscus*, and others comparable with such species as *A. ibex* (Waagen), *A. angulosus* (Waagen), and *A. spiniger* (Krafft). Several more small examples are attached to large specimens of *Keyserlingites*, of which the collection includes nine fine examples, belonging to a new species, near to *K. middendorfi* (Keyserling).⁷ The Spitsbergen form, however, has a simpler suture-line, with only bifid external lobe.

The numerous specimens here referred to *Prosphingites*? include

¹ Ib., p. 123, pl. ix, fig. 4.

² Ib., p. 58, pl. v, fig. 2.

³ Loc. cit., 1886, p. 85, pl. xi, figs. 1-6.

⁴ Loc. cit., 1913, p. 25, pl. iv, fig. 3.

⁵ *Lethæa Geogn.*: II. Mesozoic; vol. i, Trias, pt. ii, 1905, pl. xxviii, fig. 2.

⁶ Loc. cit., 1886, pl. x, fig. 19a-b, p. 80. Öberg's original figure (loc. cit., pl. iii, fig. 6) is much nearer the new form.

⁷ In Mojsisovics, loc. cit., pl. iii, p. 38. The form figured and described by Diener ("The Cephalopoda of the Muschelkalk": *Mem. Geol. Surv. India, Pal. Indica*, ser. xv, Himalayan Fossils, vol. ii, Trias, pt. ii, 1895, p. 28, pl. v, fig. 7) as *Ceratites* sp. ind. ex aff. *C. middendorfi* (Keyserling) from the Muschelkalk, like his Middle Triassic *Sibirites prahlada* (ib., p. 37, pl. vii, fig. 5), have nothing to do with the Lower Triassic forms here discussed. There is not one Muschelkalk form found in association with the latter at Spitsbergen.

several new forms, externally resembling such species as *Nannites herberti* Diener and *N. hindostanus* Diener,¹ but with toothed lobes. *Prosphingites austeni* Hyatt & Smith² has a similar suture-line, but is too involute; on the other hand, some of the specimens greatly resemble the inner whorls of *Prosphingites czekanowskii* Mojsisovics,³ though in this form, as also in *Paranannites aspenensis* Hyatt & Smith,⁴ the external lobe is too complicated.⁵ The radial folds and pseudo-constrictions of some examples are pronounced; other forms are quite smooth and globose, but they agree in suture-lines. Only one example was attached to a typical *Arctoceras*, but many small specimens came out of the matrix of a large specimen of *A. lindströmi* (Mojsisovics) from "lowest line of nodules in flags, 400–450 feet above camp, Mt. Marmier".

The numerous forms referred to above as gen. nov. (*Danubites*?, *Xenodiscus*?) belong to a group of which "*Dinarites*" *evolutus* Waagen,⁶ and *Ceratites minutus* Diener⁷ [non *Dinarites minutus* Waagen] probably are examples. The former has been compared with *Bittnerites*, and also with *Xenodiscus*, and some forms referred to the latter genus by Diener, e.g. *X. cf. lissarensis* Diener⁸ and *X. comptoni* Diener,⁹ indeed, greatly resemble the later forms. But the Spitsbergen Ammonites, probably, are nearly related to *Danubites*, e.g. *D. hyperboreus* (Mojsisovics), and to *Olenekites*, though the constrictions and coarse folds of the inner whorls somewhat resemble the Middle Triassic *Cuccoceras*. Again, the notched periphery of some of the more involute forms has the appearance of that of *Anasibirites ceratitoides* (Waagen),¹⁰ but the suture-line of the whole group is very close to that of the form described as *Xenaspis marcoui* by Hyatt & Smith.¹¹ There is no resemblance to the Indian forms of *Xenodiscus*, with flattened periphery, in the British Museum Collections, nor to the forms of *Xenodiscus*, recorded with *Paratirolites* and *Stephanites* from Djulfa by Stoyanow,¹² and supposed to correspond with those of the Himalayan *Hedenstræmia*-beds.

On the whole, then, the group is, perhaps, closer to the Arctic

¹ "The Cephalopoda of the Lower Trias": loc. cit., Himalayan Fossils, vol. ii, pt. i, 1897, pp. 68, 69, pl. vii, figs. 2, 3.

² Loc. cit., 1905, p. 72, pl. vii, figs. 1–4.

³ Loc. cit., 1886, p. 64, pl. xv, figs. 10–12.

⁴ Loc. cit., 1905, p. 81, pl. viii, figs. 1–15; pl. lxxiii, figs. 1–30.

⁵ *Prosphingites ali* Arthaber (*Albania*, 1911, pl. xxii, fig. 6) has a similar external lobe, but the saddles and lobes are only about half as high in the Spitsbergen species. *Paranannites mediterraneus* Arthaber (ib., pl. xviii, fig. 8), on the other hand, has quite a different suture-line.

⁶ Loc. cit., 1895, p. 32, pl. x, fig. 3.

⁷ "Triad. Ceph. Fauna d. Ostsibir. Küstenprovinz": *Mém. Com. Géol. St. Pétersb.*, vol. xiv, No. 3. 1895, p. 15, pl. ii, fig. 6.

⁸ Loc. cit. (Kashmir, 1913), p. 5, pl. i, fig. 11.

⁹ Ib., p. 10, pl. ii, fig. 7.

¹⁰ Loc. cit., 1895, p. 115, pl. viii, fig. 10.

¹¹ Loc. cit., 1903, p. 116, pl. vii, figs. 26–33.

¹² "On the Character of the Boundary of Palæozoic and Mesozoic near Djulfa": *Verh. Russ.-Kais. Min. Ges.*, ser. II, vol. xlvi, 1909, pp. 86, 87.

Danubites than to any other development, and it should be mentioned that Waagen's *D.?* *evolutus* also is associated with *Anasibirites*. The young of some of the Spitsbergen forms also resemble the example figured by Diener¹ as *Danubites* nov. sp. ind., with evolute whorls, parabolæ-like costæ, and constrictions like Diener's Fig. 7a. Only the suture-line in this form of *Danubites* has the external lobe subdivided, whereas in the Spitsbergen group it is entire, like that of *Ceratites minutus* Diener non Waagen. The largest specimen of the group, a form very near to *D.?* *evolutus* Waagen, attains a diameter of 70 mm.

Apart from over ninety specimens of this group of *Danubites* ? the collections include some more or less unidentifiable impressions of similar Ammonites in a black limestone, possibly from the "Lower Lamellibranch zone"; also some in a softer, more brownish rock that may belong to the "flags above the nodule bed", with the large ribbed *Pseudomonotis*. It should be mentioned, however, that according to Stolley,² a very hard, splintery limestone occurs in large nodules above the *Posidonomya* shales. Stolley would include this in the Lower Muschelkalk, and considers *Arctoceras lindströmi* and *A. costatum* to belong to this bed. But the large specimen of *A. lindströmi*, referred to above, from the "lowest line of nodules in flags, 400–450 feet above camp, Mt. Marmier", has *Posidonomya* attached to the matrix, and the writer cannot separate it from the fauna of the *Posidonomya* nodules. The impressions referred to represent evolute more or less smooth shells, and their attribution to *Danubites*, of course, is quite uncertain. One specimen in a soft, dark shale resembles *Meekoceras* (*Gyronites*) *nathorsti* J. Böhm,³ but the periphery is not shown.⁴

Two specimens require special mention. They were discovered, accidentally, in what almost is a bone-bed, among portions of Labyrinthodonts and Coelacanthid fish-remains, associated with *Posidonomya*, to judge by other specimens, and undoubtedly of the age of the *Posidonomya* shales. One of these specimens is a crushed and incomplete example of ? *Gyronites*, comparable with *G. aplanatum* (White),⁵ which also has been recorded from the *Arctoceras* bed by Stolley⁶; the other is a fragment, resembling "*Danubites*" *strongi* Hyatt & Smith⁷ in its angular periphery, in ornament, and in evolution, but having the lateral folds a little closer.

¹ Loc. cit., (1895, Ostsibir.), pl. i, fig. 7.

² "Zur Kenntn. d. Arkt. Trias": *N. Jb.*, vol. i, 1911, p. 122.

³ "Üb. Trias Verstein. v. Bell-Sunde auf Spitzbergen": *Arkiv f. Zool.*, vol. viii, 1913, No. 2, p. 11, pl. i, figs. 17–19.

⁴ From Professor Gregory's section I it will be seen that there are 600 feet of black shales and yellow flags (from which these *Danubites* may have come) between the undoubtedly Lower Triassic "Nodule Bed" (C₁) and the probably Middle Triassic "Earthy Limestone" (D₁).

⁵ See Hyatt & Smith, loc. cit., 1905, p. 146, pl. xi.

⁶ Loc. cit., 1911, p. 123, pl. ix, fig. 5.

⁷ Loc. cit., 1905, p. 165, pl. ix, figs. 4–10.

One slab from the "Nodule bed" of the Trident, Sassendal, full of *Posidonomya mimer*, and containing, in addition to *Arctoceras*, a fragment of one of the species of the gen. nov. (*Danubites* ?), also includes a portion of what Dr. A. Smith Woodward considers to be *Belonorhynchus wimani* A. Smith Woodward.¹ The writer, at first, thought that these plentiful *Danubites* ? might be what Wiman² calls the commonest Ceratite of the "fish-bed". Other fish-remains in the British Museum (*Acrolepis*), and some Coelacanthid remains associated with *Arctoceras* and *Posidonomya mimer*, also are preserved in the black limestone that must have come from nodules in the *Posidonomya* shales. But only a few isolated specimens of *Danubites* ? are found associated with *Arctoceras* and *Posidonomya*, whereas the nodules in which these *Danubites* ? occur in clusters are crowded with a very convex *Pseudomonotis*. This also characterises the matrix of *Anasibirites* and *Keyserlingites*, but it does not seem to be found in the slabs with *Posidonomya mimer*, where a less convex and smoother form (still of the *P. boreas* type) rarely occurs.

Professor Wiman³ recorded his Labyrinthodont remains from the lower part of the *Posidonomya* shales of Mt. Marnier, and thought that the "fish-bed", not quite at the base of the Trias, might not represent the exact horizon from which Mojsisovics' *Arctoceras* fauna was obtained.⁴ From the evidence of the specimens labelled "Lower Nodule Bed", and from Professor Gregory's section I, it would appear as though both the typical *Arctoceras* fauna, recorded by Mojsisovics, corresponding with the "*Posidonomya* nodules" aforementioned, and the *Anasibirites*—*Keyserlingites*—*Prionites*—*Goniodiscus* assemblage, recorded here from the "*Pseudomonotis* nodules", occurred at about the base of the "*Posidonomya* shales". The fish-bed of Professor Wiman⁵ also may be near this horizon, C₁.

Whether the whole of the 600 feet of "*Posidonomya* shales" above this horizon belong to the Lower Trias is doubtful. The "Lower Saurian horizon" of Professor Wiman, 300 feet above the fish-bed, may coincide with the bed from which ? *Gyronites aplanatus* and ? *Danubites strongi* have been recorded, those species being known to occur in the "*Meekoceras*" beds of Idaho and California. Hyatt & Smith⁶ record *Anasibirites* from the same beds, so that

¹ "Notes on some Fish-remains from the Lower Trias of Spitsbergen": *Bull. Geol. Inst. Univ. Upsala*, vol. xi, 1912.

² "Ichthyosaurier a. d. Trias Spitzbergens": *Bull. Geol. Inst. Univ. Upsala*, vol. x, 1910-11, Nos. 19 and 20, p. 127.

³ Loc. cit., 1910, p. 34.

⁴ Loc. cit., 1911, p. 127.

⁵ *Ib.*, p. 126.

⁶ Loc. cit., 1905, p. 49. In 1914 (*The Middle Triassic Marine Invertebr. Faunas of North America*, p. 4: Correlation Table) Professor Perrin-Smith put the Spitsbergen *Posidonomya* "Limestones" as equivalent to the *Meekoceras* Beds of the Himalayas and the *Proptychites* Beds of the Ussuri, that is to say,

the two species mentioned (the identification of which is not definite) may belong to the uppermost Lower Trias. In the nodule bed a doubtful *Flemingites* has been found, and the *Anasibirites* and *Keyserlingites* are characterized by simple sutures, so that horizon C_1 may very probably be somewhere near the border-line between the *Flemingites* beds below and the *Stephanites* zone above.¹ The latter probably includes the lower half or more of the *Posidonomya* shales, but an exact correlation is impossible in the present state of our knowledge.

(To be continued.)

Precambrian Para-Gneisses of Southern Eyre Peninsula, South Australia.

By C. E. TILLEY, Emmanuel College, Cambridge.

(Concluded from p. 259.)

4. ORIGIN OF THE GARNET GNEISSES.

THE composition of the garnet gneisses already described allows them to be treated collectively in a discussion of their origin. It will be clear from the foregoing account that the mineralogical composition and the textures developed are those characteristic of the highest grades of metamorphism. They are, therefore, to be included amongst the Kata-zone gneisses of Grubenmann. The pronounced banding in these rocks must be interpreted as a result of initial differences in composition of the original sediments. This banding therefore represents the bedding and has been preserved through the various stages of metamorphism, eloquent testimony that the amplitude of diffusion in metamorphism is in general of quite limited dimensions.

far too low in the Lower Trias. On the other hand, the Siberian Olenek Beds, probably, like the *Stephanites* zone of the Salt Range and the Himalayan *Hedenstræmia* Beds, can be correlated with the Spitsbergen *Posidonomya* Shales or at least their lower part (see also Diener, "Das Alter der Olenekschichten Sibiriens": *Centralbl. f. Min.*, etc., 1908, p. 233).

¹ The Lower Triassic fauna of Këira in Albania, that Diener (Kashmir, 1913, p. 121) considers to be homotaxial with the *Hedenstræmia* stage of India, and that, at least in part, corresponds with the *Columbites* fauna of Idaho, shows a striking resemblance to the apparently contemporaneous fauna here described, but contains many higher (and later ?) types. Arthaber's treatment of this fauna, as his whole classification, is not very fortunate (see L. F. Spath, "Notes on Ammonites": *GEOLOGICAL MAGAZINE*, Vol. LVII, 1919, p. 224); but the affinities of e.g. some of the forms that Arthaber includes in his heterogeneous *Dagnoceras* (*Arctoceras*!) with certain Spitsbergen Ammonites here referred to *Anasibirites*, *Goniodiscus*, *Prionites*, etc., are most interesting. They show that, as mentioned above, the "*Meekoceras*" and "*Xenodiscus*" of the *Stephanites* zone probably are only heterochronous homœomorphs of the lower, true *Meekoceras* and *Xenodiscus*. In the case of the latter, the forms of the *Ophiceras* layer may have to be separated generically both from the Permian type and from the Upper Eotriassic forms, that is to say, there are at least three independent developments that successively take on the "*Xenodiscus*" characters.

That the rocks have developed under a not inconsiderable shearing stress is evidenced by the development of biotite, quartz and graphite in flakes elongated in a plane of foliation, which is here coincident with the banding surface, thus serving to accentuate the banding. We have already referred to the development of garnet in lenticular grains with noteworthy elongation parallel to the foliation, and to the occurrence of uniformly oriented sillimanite.

This streaky development of sillimanite in orthoclase is strongly suggestive of development under actual shearing movement.

Granulation of the enclosing mineral might be expected in such cases, but it is quite clear that if this movement has taken place the evidence of granulation of the enclosing feldspar has been destroyed by healing. The most probable explanation appears to be that crystallization of sillimanite occurred under conditions permitting shearing movement, and at temperatures sufficiently high to inhibit granulation of feldspar.

To the case of garnet the same remarks may apply. The lens-like character of the garnet porphyroblasts, with their longer axes parallel to the foliation, is a feature of a number of the Sleaford gneisses. Here, again, the enclosing mineral shows perfect optical continuity at the periphery of the garnet grains. However this may be, it is quite clear that in many of the garnet grains the elongate character cannot be due to any rolling out of original garnet crystals, and in so far as this is true, it shows that the rocks have been developed under sufficient shearing stress to elongate a mineral so high in the crystalloblastic series. Even in the case of certain abnormally elongate garnet lenticles, it must be conceded that any postulated rolling out was involved in the same epoch of metamorphism, and before the temperature had fallen sufficiently to allow of granulation. Shearing stress has therefore played a not unimportant rôle in the development of these gneisses. The element of stress has also left its mark after crystallization had been completed, the clues to which are the development of rows of fluid pores in quartz grains at right angles to the direction of foliation, and in the case of the Hutchison garnet gneisses, the extensive cataclasis. This cataclasis is associated only with the gneisses of the northern area, and is absent in the Sleaford rocks.

It was pointed out in a previous paper that the dolomites associated with these gneisses showed no evidence that shearing stress had played any important rôle. The propriety of these two apparently conflicting statements calls for some remark. In the case of pure dolomites we are concerned with a mineral whose habit is not favourable to the development of elongate crystals, and there is a further factor involving the facility with which the carbonate minerals recrystallize. With regard to mineralogical evidence of shearing stress, the abundant presence of the anti-stress mineral forsterite indicates that the hydrostatic element was dominant.

As has been pointed out by Harker,¹ shearing stress has a

¹ Harker, Pres. Address Geol. Soc., 1918, p. lxxix.

maximum value which is a function of temperature, and this maximum stress diminishes with rising temperature, so that at very high temperatures the stress element in metamorphism may be quite subordinate. During the metamorphism of the sediments under consideration, and at the temperature prevailing, shearing stress was adequate to orient biotite, quartz, and flakes of graphite, and in some cases elongate individual garnet crystals during their crystallization in the rigid garnet gneisses, but only a granular texture was imparted to the dolomite rocks.

Doubtless in general an important factor in this different behaviour is the position of dolomite with regard to quartz and biotite in the crystalloblastic series.

That at a given temperature the upper limit of shearing stress is lower for the carbonate rock than for the more rigid quartz-felspathic type, seems undoubted, and the essential factor in this behaviour is the ease with which the carbonate minerals recrystallize, and the consequent tendency to a viscous flow limiting the range of shearing stress. The presence of carbon dioxide as a solvent in rocks of this class contributes to this end.

As to the nature of the original sediments from which these garnet gneisses are derived, all traces of original clastic structure have been destroyed by the complete recrystallization involved. Nor in the nature of the case are the evidences of progressive metamorphism by which the succession of mineralogical changes might be determined clearly defined. The mineralogical composition of the group is that which might be expected in the metamorphism of sediments of the composition of shales, grading into more quartzose types, and even merging into arkoses, where the felspathic constituent is dominant.

The two prime constituents of all the rocks are quartz and feldspar, and the important additional minerals are biotite, garnet, sillimanite, and spinel.

<i>Analysis.</i>	<i>Sleaford gneiss.</i>	<i>Vermont slate.</i>	<i>Norm.</i>	<i>Osann class.</i>
SiO ₂	64.35	62.37	Quartz	S = 70.4
Al ₂ O ₃	16.21	15.43	21.7	A = 5.5
Fe ₂ O ₃	1.01	1.34	Orthoclase	C = 1.6
FeO	6.91	5.34	31.1	F = 12.0
MgO	2.95	3.14	Albite	M = —
CaO	1.35	0.77	14.1	T = 3.4
Na ₂ O	1.70	1.14	Anorthite	K = 1.5
K ₂ O	5.25	4.20	6.7	
H ₂ O +	0.32	3.71	Corundum	a = 5.8
H ₂ O —	0.14	0.34	5.4	c = 1.7
other			Hypersthene	f = 12.5
constituents	n.d.	2.02	19.3	
	100.19	99.80	Magnetite	
			1.4	

An analysis of a less quartzose variety of the type β gneisses has been made.

The constituents are perthitic orthoclase quartz, plagioclase garnet, biotite, magnetite, and a few flakes of graphite can also be detected.

The analysis of this rock is given on p. 307, and with it the analysis of a slate from Vermont.

An inspection of this analysis shows that the available criteria for a sedimentary origin are satisfied.

Magnesia and potash are in excess of lime and soda respectively. The presence of corundum in the norm to the extent of 5.4 per cent is also a partial confirmation.

The analysis is close to that of a slate from Vermont, described by T. N. Dale,¹ and the correspondence would be still closer if the slate analysis were recalculated after removal of excess water.

A comparison with the analyses listed by Grubenmann indicates its grouping with Class II—the aluminium silicate gneisses. If the procedure of Grubenmann be adopted in representing graphically the composition of the gneisses by an adaptation of the Osann projection, we have the following triangular diagram (Fig. 3).

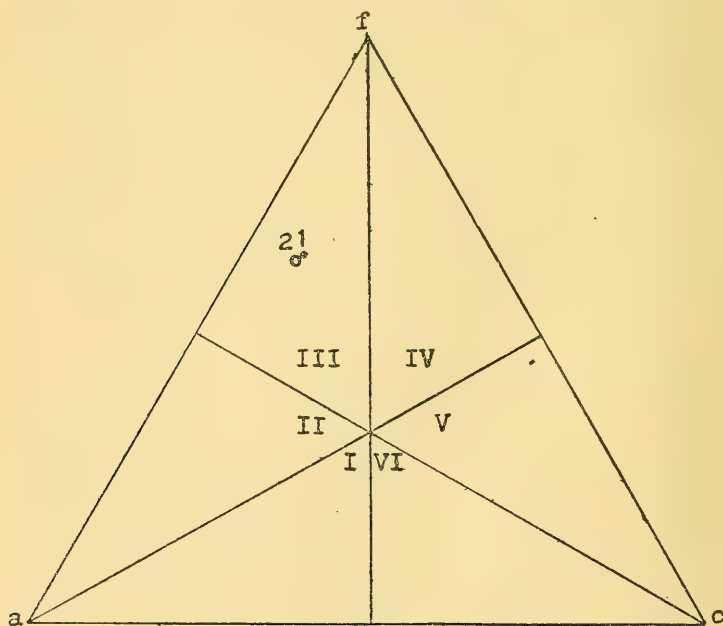


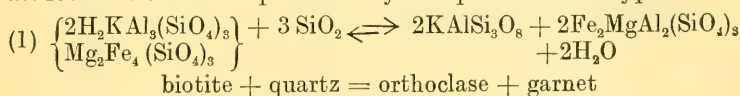
FIG. 3.—(Osann.) 1. Garnet gneiss, Sleaford Bay. 2. Mean position of the aluminium silicate gneisses.

¹ Clarke, *Bull. U.S.G.S.*, No. 419, p. 211.

The parameters correspond closely with those for the "group mean" of the analyses cited by Grubenmann.

The abundant minerals garnet and sillimanite serve as indices of the origin of the dominant potash felspar. The high-grade metamorphism of argillaceous material results usually in the formation of potassic felspar from the more aluminous constituents as the micas, either sericite or biotite. It is obvious that the formation of new felspar from these constituents involves the setting free of an excess of alumina to be disposed of. In these rocks this has appeared either as garnet or sillimanite or more rarely spinel.

Dealing first with garnet. This is essentially an almandine type in which the FeO constituent is dominant, as the analysis shows. Its formation can be represented by an equation of the type

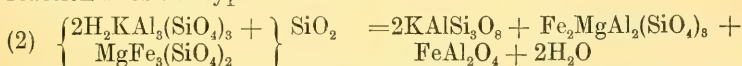


The excess alumina is here combined with the iron magnesia constituents in garnet.

The validity of an equation of this nature is evident by the relationships of certain garnets as seen in thin slices, where its association with biotite and quartz is one of genetic significance.

The reversibility of this equation is postulated at least for those cases where the degradation of garnet to biotite is to be observed, the potash being obviously derived from neighbouring orthoclase.

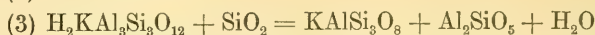
In some of the rocks garnet occurs in association with green spinel, and this relationship is genetic (cf. Fig. 2 (b)). The equation for this reaction is of the type¹



Those types in which quartz and felspar are the chief constituents and garnet and sillimanite very subordinate, can obviously only have derived that amount of felspar from biotite or sericite in accordance with the amount of alumina set free to be absorbed in garnet and sillimanite. The felspar in excess of this amount must be derived by the recrystallization of original felspar, and where this was large the original sediment was an arkose.

¹ In these equations the *quantitative* proportions of orthoclase to garnet, sillimanite, and spinel will obviously depend on the ratio H : K in the mica involved. In this, and following equations, the mica must be regarded as *mechanical* mixtures of sericite, and biotite of the composition shown in equation (1). For simplicity the gross composition of these mixtures is shown. Whether Clarke's view, or the hypothesis of Tschermak for the constitution of the micas is adopted, it is quite clear that the main types muscovite and biotite form mix crystals only to a very limited degree. In a recent paper in a study of a large number of analyses of the mica group, H. E. Boeke ("Die Grenzen der Mischkristallbildung in Muscovit und Biotit": *Neues Jahrbuch*, 1916, pp. 83-117) shows that the compositions of muscovite and biotite are to be represented in two distinct and separate fields, each of which is quite limited in extent.

The occurrence of sillimanite in these rocks shows that it has arisen (a) from sericite

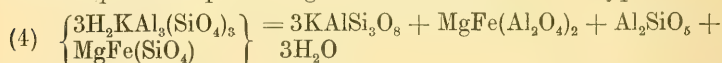


This equation explains the genetic association of needles of sillimanite in orthoclase where ferromagnesian constituents are not present.

(b) from biotite.

In these cases the sillimanite is intimately associated with garnet, and in certain cases the ferromagnesian constituents have been absorbed in spinel to the exclusion of garnet.

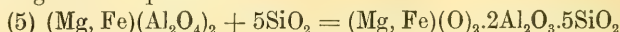
The equation representing this association is of the type



It is not improbable that some of the magnetite associated with sillimanite in similar cases has been derived by a degradation of the biotite molecule.

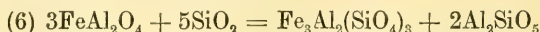
The above equation is of a type expected only in the highest grades of metamorphism, and it is of interest to compare it with the products obtained by direct fusion of biotite. Bäckström, on fusion of biotite, found among the products olivine, leucite, spinel, and glass, and Doelter records the same products with the exception of leucite. The actual products obtained would appear to depend on the composition of the mica, and in highly aluminous micas olivine would probably not appear. According to Vernadsky¹ muscovite yields corundum and sillimanite on fusion. These products are very similar to those shown in the equation above, and afford an interesting parallel to the processes at work in high-grade metamorphism.

The occurrence of spinel calls for some remark. Whenever this mineral is present it is surrounded by a shell of garnet or sillimanite, and it has not been observed in direct contact with quartz, although this may be abundantly present in the rock. This is as might be expected, as its union with silica would give rise to cordierite according to the equation



This reaction is doubtless a reversible one, and if so the dissociation temperature must exceed those temperatures normally obtaining in high-grade metamorphism.²

A spinel of composition near hercynite, under the same condition, would yield almandine and sillimanite, assuming the pure iron cordierite has no stable existence.



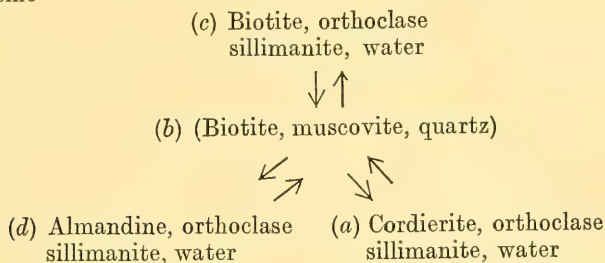
Although cordierite has been carefully looked for in these rocks, no trace of it has been observed.

¹ Cf. Clarke, *Bull. U.S.G.S.*, No. 616, p. 396.

² Artificial cordierite dissociates on melting at atmospheric pressures (Rankin and Merwin, *Amer. Journ. Sci.*, vol. xlv, 1918, pp. 301-25).

In the garnet-cordierite-sillimanite gneisses the iron-magnesia constituents of the rock are allotted between garnet, cordierite, and biotite.

The equilibria between these minerals can be represented by the scheme



and the minerals of the systems (a), (c), and (d) are found together. In the rocks under discussion, however, there has been some prevailing condition by which the equilibria have been driven completely from (a) to (c) and (d).

Whether this is connected with the very high ferrous iron content of the rock compared with magnesia, and the possible instability of an iron-rich cordierite, must await further investigation.

Correlation of the garnet gneisses with similar gneisses in other areas.

Rocks of this type can be matched in pre-Cambrian tracts in other parts of the world. The most striking analogues are the garnet gneisses of the Grenville series of North America.

Adams¹ describes garnet gneisses of the sediment type associated with crystalline limestones in the region north of the island of Montreal, Quebec, and more recently in the Haliburton-Bancroft area of Ontario.²

These rocks are extensively developed in the Grenville series in the Adirondack region of New York, and have been described by Kemp,³ Smyth, Cushing, and others.

The field relations and petrographical constitution of the rocks described by these investigators are remarkably similar to those of the rocks described in the foregoing.

Metamorphosed sediments of this type containing a green spinel have been studied from various localities. Spinel is developed in the well-known contact rocks surrounding the tonalite of the Mount Aviole region in the Eastern Alps as described by Salomon.⁴ The references to the earlier literature will be found in a paper by J. J. H. Teall.⁵ More recently Sauerbrei⁶ has studied sedimentary gneisses

¹ Adams, *Amer. Journ. Sci.*, vol. 1, 1895, pp. 58-69.

² Adams and Barlow, *Mem. No. 6, Geol. Surv., Canada*, 1910, pp. 173-91.

³ Kemp, *Amer. Assoc. Adv. Sci.*, 1900, pp. 157-84.

⁴ Salomon, *Zeit. d. deutsch. geol. Gesell.*, vol. xlii, 1890, s. 450.

⁵ Teall, *Proc. Geol. Assoc.*, vol. xvi, 1899, pp. 61-74.

⁶ Sauerbrei, *Neues Jahrbuch*, vol. xxxiv, 1912, pp. 1-41.

containing this mineral, and in the Phillipsburg Quadrangle, Montana, Calkins and Emmons¹ have described garnet-cordierite gneisses of which the same mineral is a constituent. The modes of occurrence, and associations of all these rocks, indicate that spinel is a product of the highest grades of metamorphism, and appears in rocks subject to intense thermal alteration or as members of Grubenmann's Kata-zone.

SUMMARY.

1. Garnet gneisses of sedimentary origin are described from the oldest group of sediments recognized in Southern Eyre Peninsula, South Australia. The high-grade metamorphism which these rocks have undergone has resulted in the development of felspar, garnet (almandine), sillimanite, and green spinel.

2. The mineralogical association of these constituents is described, and their genetic relations are discussed.

3. A sedimentary origin of these gneisses is attested by their interbanding with undoubted sediments, their mineralogical composition, and lastly by chemical analysis.

4. In the garnet gneisses developed in the Grenville series of North America, notably those of the Adirondack region, and in the province of Quebec, these para-gneisses find their most striking analogues.

EXPLANATION OF PLATE III.²

FIG. 1.—Garnet-sillimanite Gneiss, Mine Creek, Hundred of Hutchison. $\times 32$ diameters. The constituents are garnet, biotite, sillimanite, orthoclase, and quartz. The features illustrated in the photomicrograph are the development of elongate garnet porphyroblasts, the poikiloblastic texture, and the transverse fissures in the garnet occupied by biotite, the degradation product. Sillimanite is also seen in bunched aggregates included in orthoclase.

FIG. 2.—Garnet Gneiss, Mine Creek, Hundred of Hutchison. $\times 32$ diameters. The constituents are garnet, biotite, sillimanite, orthoclase, plagioclase, quartz, green spinel, and magnetite. The features noted in the photomicrograph are the development of a system of cracks in the garnet grains, parallel to the foliation of the rock, and the association of green spinel and sillimanite (spinel included within sillimanite in one case) as inclusions in the largest garnet crystal shown.

¹ Emmons and Calkins, Prof. Paper No. 78, *U.S.G.S.*, 1913, p. 39.

² Issued with June number.

Notes on the Fauna of the Lower Devonian Beds of Torquay.

By F. R. COWPER REED, Sc.D., F.G.S.

Part II. BRACHIOPODA.

Orthis (*Schizophoria*) *provulvaria* Maurer.

1864. *Orthis hipparionyx* ? Davidson (pars.), *Mon. Brit. Dev. Brach.*, vol. iii, p. 90, pl. xvii, fig. 10 (excl. cet.).
 1882. *Orthis hipparionix* or *striatula* Etheridge, *GEOLOGICAL MAGAZINE*, p. 156, Pl. IV, Fig. 8.
 1882. *Spirifera cultrijugata* ? Etheridge, *ibid.*, p. 155, pl. iv, fig. 9.
 1893. *Orthis provulvaria* Maurer, *Neues Jahrb. f. Miner. Geol.*, i, p. 7, t. iii, figs. 1-4.
 1904. *Orthis* (*Schizophoria*) *provulvaria* Drevermann, *Palæontographica*, Bd. I, p. 267, t. xxx, figs. 29, 30 ; t. xxxi, figs. 11-19.
 1920. *Orthis* (*Schizophoria*) *provulvaria* Reed, *Journ. Torquay Nat. Hist. Soc.*, vol. ii, No. 6, pp. 340, 341.

Drevermann has already described and figured this species, and there can be no doubt that the shell from Smugglers' Cove described by Etheridge as "*O. hipparionix* (*sic*) or *striatula*" belongs to it. There are several much better examples in the Sedgwick Museum from Smugglers' Cove, which fully confirm this conclusion. The specimen from Looe, figured by Davidson (*op. cit. supra*) as *O. hipparionyx* ? is believed by Drevermann to belong to *O. provulvaria*, but he does not mention Etheridge's shell from Smugglers' Cove. There is also one imperfect example in the Sedgwick Museum from the New Cut. Williams and Breger¹ consider Schnur's² *Orthis hipparionyx* (*non* Vanuxem) from Prüm in the Eifel, to be identical with Hall's³ *Schuchertella woolworthana* from the Lower Helderberg of New York.

Horizon.—Lower Devonian (Staddon Grits).

Localities.—Smugglers' Cove, Torquay (S, 58) ; New Cut, Torquay (S. 30).

Orthis (*Dalmanella*) *circularis* Sowerby ?

Sowerby's type⁴ of this species was from the Rhenish Lower Devonian, but the name seems to have been subsequently applied to various members of a group of species which are difficult to distinguish when the material is poorly preserved, as is the case with the Torquay specimens. The synonymies which Kegel⁵ and Williams & Breger⁶ have given for this species may be questioned, and Fuchs⁷ has recently split up the group into a number of distinct species which were previously regarded as identical with *O. circularis* or merely varieties of it.

Horizon.—Meadfoot Beds.

Locality.—Meadfoot, Torquay.

¹ Williams & Breger, Prof. Paper 89, *U.S. Geol. Surv.*, 1916, pp. 34, 39.

² Schnur, *Palæontographica*, vol. iii, 1853, p. 217, pl. xl, figs. 1a-c.

³ Hall, *Tenth Ann. Rep. New York State Cab. Nat. Hist.*, 1857, p. 48, figs.

⁴ Sowerby, *Trans. Geol. Soc.*, ser. II, vol. vi, 1842, p. 409, pl. xxxviii, fig. 12.

⁵ Kegel, *Abh. k. preuss. geol. Landesanst.*, N.F., Heft lxxvi, 1913, p. 101; t. v, fig. 7.

⁶ Williams & Breger, *op. cit.*, 1916, pp. 59, 60.

⁷ Fuchs, *Abh. k. preuss. geol. Landesanst.*, N.F., Heft lxxix, 1915, pp. 8-16.

Stropheodonta Murchisoni (D'Archiac & de Verneuil).

1840. *Orthis Murchisoni* D'Archiac & de Verneuil, *Trans. Geol. Soc.*, ser. II, vol. vi, p. 371, pl. xxxvi, fig. 2.
 1882 ? *Strophomena Murchisoni* Barrois, *Mem. Soc. Geol. Nord.*, ii, 1, p. 241, pl. ix, fig. 6.
 1887. *Strophomena Murchisoni*, Bécлар, *Bull. Soc. belge. geol. Pal. Hydr.*, 1, p. 89, pl. iv, figs. 17-19.
 1902. *Stropheodonta Murchisoni* Drevermann, *Palæontographica*, vol. xlix, p. 110, t. xiv, figs. 4-6, 7 (?), 8.

This species was recorded by Kayser¹ in 1889 from the Meadfoot Beds below Kilmorie, and by Upfield Green² from Cornwall. There are several examples from Kilmorie, and possibly one from Smugglers' Cove, in the Sedgwick Museum, but none are perfect and most are distorted. The characteristic coarse ribbing is, however, well seen, and in one case the fine radial striation between the ribs, which is specially mentioned by D'Archiac and de Verneuil³ in a variety from Asturias (separated by Oehlert⁴ as a distinct species, *Str. diffusa*), is well preserved. Drevermann (op. cit. *supra*) says the ribs are sometimes simple and sometimes divided, and that at the submarginal geniculation of the shell they either disappear or are resolved into bundles of fine riblets. In one of our specimens the ribs become obsolete before reaching the margin, but they seem nearly always to be simple. There is one example of this species in the Jermyn Street Museum ($\frac{2}{3}$), labelled simply "Torquay", but probably it came from Meadfoot.

The group of species to which *Str. Murchisoni* belongs is compact and well differentiated, and it includes *Str. Sedgwicki*, D'Arch. and de Vern., *Str. acutiplicata* (Oehl. & Dav.),⁵ *Str. diffusa* Oehl. (if separated from *Str. Murchisoni*), *Str. virgata* Drev.,⁶ *Str. fascigera* Drev.,⁷ and the American forms *Str. galatea* (Billings),⁸ and *Str. parva* Hall.⁹

Horizons.—(1) Meadfoot Beds ; (2) Red Beds (Staddon Grits).

Localities.—(1) Kilmorie (S. 32, 54) ; (2) Smugglers' Cove (S. 59) ; (3) "Torquay" (? Meadfoot) $\frac{2}{3}$ M.P.G.

Stropheodonta Sedgwicki (D'Arch. & de Vern.) var. *rudis* Kegel.

This species,¹⁰ which has been described in some detail by Drevermann,¹¹ and compared with several other species of Lower

¹ Kayser, *Neues Jahrb. f. Min. Geol.*, vol. i, 1889, p. 188.

² Upfield Green, *GEOL. MAG.*, Dec. V, Vol. I, 1904, p. 406.

³ D'Archiac & de Verneuil, *Bull. Soc. Géol. France*, ser. II, vol. ii, 1845, p. 477, pl. xv, fig. 7.

⁴ Oehlert, *Bull. Soc. Géol. France*, ser. III, vol. xxiv, 1896, p. 868.

⁵ Oehlert & Davoust, *Bull. Soc. Géol. France*, 3, vol. vii, 1879, p. 708, pl. xiv, fig. 3.

⁶ Drevermann, *Palæontographica*, Bd. xlix, 1902, p. 111, t. xiv, figs. 10, 11.

⁷ *Ibid.*, p. 112, t. xiv, fig. 12.

⁸ Clarke, *Mem. 9, U.S. State Mus.*, 1908, p. 188, pl. xxxv, figs. 15-26.

⁹ Hall, *Palæont.*, New York, vol. iv, 1859, p. 85, pl. xi, figs. 5, 11.

¹⁰ D'Archiac & de Verneuil, *Trans. Geol. Soc.*, ser. II, vol. vi, 1840, p. 371, pl. xxxvi, fig. 1; Oehlert, *Bull. Soc. Géol. France*, ser. III, vol. xvii, 1899, p. 776, pl. xix, fig. 8; pl. xxi, fig. 1.

¹¹ Drevermann, *Palæontographica*, Bd. l, 1904, No. 6, p. 271, t. xxxi, figs. 21-6.

Devonian age, is closely allied to *Str. Murchisoni* and *Str. virgata* Drev.,¹ but it varies somewhat in the development and number of its ribs, and consequently Kegel² has established the variety *rudis* for those forms possessing few and coarser ribs which occur in the Taunus quartzite. Two fragmentary valves from the Smugglers' Cove red beds have been recognized, one of which shows the cardinal region of the internal cast of a brachial valve, and both agree with Kegel's variety in the character of the ribbing rather than with the type.

Horizon.—Red Beds (Staddon Grits).

Locality.—(1) Smugglers' Cove (S. 100); small cove immediately south of Smugglers' Cove (Shannon Coll.).

Stropheodonta gigas (McCoy).

It is unfortunate that McCoy's³ type of this species, which is from Looe, is in a poor state of preservation, and only shows the external ornamentation. Davidson⁴ figured the interior of a pedicle-valve and Drevermann⁵ the interior of a brachial valve, giving at the same time a full description of the specific characters. At Meadfoot it occurs in a tough siliceous bluish cleaved slate, with numbers of *Chonetes plebeia*, *Ch. sarcinulata*, *Spirifer* sp., and *Pleurodictyum problematicum*. One specimen ($\frac{29}{40}$) in the Jermyn Street Museum, simply labelled "Torquay", occurs in the rotten calcareous, sandy rock of Kilmorie, and shows the internal cast of a pedicle valve, while another (1245) in the Ussher Collection shows the denticulations along the hinge-line of the brachial valve. It is possible that *Strophomena protæniolata* Bécclard,⁶ is identical with this species.

Horizon.—Meadfoot Beds.

Localities.—Meadfoot (S. 49, 50); East of South Bank (Ussher Coll., 1245 M.P.G.); "Torquay" (? Kilmorie) $\frac{29}{40}$ M.P.G.

Leptæna rhomboidalis (Wilckens).

1769. *Conchita rhomboidalis* Wilckens, *Nachr. Selt. Verstein.* p. 77, pl. viii, figs. 43, 44.

This well-known Silurian species, which does not seem to be specifically separable from that occurring in the Lower Devonian of Europe and America, is represented in the Sedgwick Museum by one good example from a dark grey lustrous slate, labelled "The Knoll, South of Meadfoot Sands". Williams and Breger (op. cit. p. 32, pl. viii, figs. 8–12) describe specimens of it from the Chapman Sandstone of Maine, and give references to the American literature,

¹ Ibid., Bd. xlix, 1902, No. 2, p. 111, t. xiv, figs. 10–11.

² Kegel, *Abh. k. preuss. geol. Landesanst.*, N.F., Heft lxxvi, p. 103, t. vi, figs. 1, 2.

³ McCoy, *Syn. Brit. Palæoz. Foss. Woodw. Mus.*, 1852, p. 386, pl. ii, fig. 7.

⁴ Davidson, *Mon. Brit. Dev. Brach.*, vol. iii, 1864, p. 83, pl. xvi, figs. 1–3 (non 4).

⁵ Drevermann, *Palæontographica*, Bd. I, 1904, p. 273, t. xxxii, figs. 1–4.

⁶ Bécclard, *Bull. Soc. belge Geol. Pal. Hydr.*, i, 1887, p. 93, t. v, fig. 2.

and others have described it from many Devonian localities in Europe.

Horizon.—Meadfoot Beds.

Locality.—The Knoll, South of Meadfoot Sands (S. 52).

Chonetes plebeia Schnur.

1853. *Chonetes plebeia* Schnur, *Palæontographica*, Bd. iii, Lief. 4, p. 226, t. xlii, figs. 6a-d (excl. cet. ?).
 1878. *Chonetes sarcinulata* var. *plebeia* Kayser, *Abhandl. geol. specialk. Preuss.*, Bd. ii, Heft iv, p. 200, t. xxx, figs. 13, 14.
 ? 1883 *Chonetes plebeia* Oehlert, *Bull. Soc. Géol. France*, ser. 3, vol. xi, p. 517, pl. xiv, figs. 3, 3a-c.
 1889. *Chonetes plebeia* Barrois, *Faune Calc. d'Erbray*, *Mem. Soc. Geol. Nord.*, iii, pl. iv, fig. 4.
 1889. *Chonetes plebeia* Kayser, *Abh. k. preuss. geol. Landesanst.*, N.F., Heft i, p. 63, t. vii, figs. 2-5; t. x, fig. 7.
 1897. *Chonetes plebeia* Whidborne, *Quart. Journ. Geol. Soc.*, vol. liii, p. 454, pl. xxxiii, figs. 1, 2.
 1915. *Chonetes semiradiata* Sowerby, Fuchs, *Abh. k. preuss. geol. Landesanst.*, N.F., Heft lxxix, p. 19, t. iv, fig. 11.

This small species occurs in considerable abundance in the Red Beds of the New Cut and in the slaty beds of Meadfoot, but is often distorted, and always crushed. Whidborne has also recorded *Ch. plebeia* from the Morte Slates, but Davidson made no mention of the occurrence of this species in the British Isles. It is a conspicuous form in the Lower Coblenzian of the Continent, but ranges up into the Upper Coblenzian, and perhaps higher.

Horizons.—(1) Red Beds (Staddon Grits); (2) Meadfoot Beds.

Localities.—(1) New Cut and Lincombe Drive (S. 14, 15, 16, 28) (T. $\frac{2}{6}$); (2) Meadfoot (S. 48, 49, 50, 64) (M.P.G. $\frac{2}{8}$) (M.P.G. 1208, 1210, 1211 Ussher Coll.); (4) New Drive from Hope's Farm (M.P.G. 1157, Ussher Coll.); (5) South of Hope Farm, edge of Bramblebrake (M.P.G. 1181, Ussher Coll.).

Chonetes sarcinulata Schlotheim.

The characters of this species and its separation from other allied forms have always been in doubt owing to the difficulty of deciding what fossil Schlotheim intended to designate by this name.¹ Davidson² put it (together with *Ch. sordida* (Phill.³) as a probable synonym of *Ch. hardrensis* Phill., which is typically a Carboniferous species. But if we adopt Kayser's⁴ views on the matter, we appear to have it represented in the Torquay district at Meadfoot and below Kilmore, though, unfortunately, none of the specimens which I have examined are well preserved. Kayser⁵ himself recorded it from the Meadfoot Beds below Kilmore, and there is a specimen from this locality ($\frac{2}{8}$) thus labelled by De Koninck in 1873 in the

¹ Williams & Breger, Prof. Paper 89, *U.S. Geol. Surv.*, 1916, p. 47.

² Davidson, *Mon. Brit. Dev. Brach.*, vol. iii, 1864, p. 94.

³ Phillips, *Palæoz. Foss. Dev. Cornw.*, p. 62, pl. xxv, fig. 104.

⁴ Kayser, *Abh. k. preuss. geol. Landesanst.*, N.F., Heft i, 1889, p. 62, t. vii, figs. 4, 6-8; t. x, fig. 8.

⁵ Kayser, *Neues Jahrb. f. Min. Geol.*, vol. i, 1899, p. 188.

Jermyn Street Museum. Whidborne¹ has doubtfully referred some specimens from the Morte Slates of Treborough to this species. Fuchs² has separated off some of the shells figured by Kayser under this name as a new species, *Ch. oblonga*, and also considers *Ch. subquadrata* Roem. to be merely a variety of *Ch. sarcinulata*, but it is difficult to make out the alleged specific differences in the Torquay specimens. It is much to be regretted that there exists such difference of opinion and uncertainty with regard to its specific distinction, for Gurich³ states that it is the most widely distributed species of the Lower Devonian. The American species, known as *Ch. novascoticus* Hall,⁴ may perhaps be identical.

Horizon.—Meadfoot Beds.

Localities.—Meadfoot (S. 48, 49, 50); below Kilmore (2 $\frac{9}{16}$ M.P.G.).

Camarotæchia daleidensis (Roemer).

1844. *Terebratula daleidensis* F. Roemer, *Rhein. Uebergangsgeb.*, p. 65, t. i, fig. 7.
 1853. *Terebratula daleidensis* Schnur, *Palæontograph*, vol. iii, p. 172, t. xxii, fig. 1.
 1887. *Rhynchonella daleidensis* Bécclard, *Bull. Soc. belge geol. Pal. Hydr.* i, p. 85, pl. iv, figs. 9–11.
 1899. *Rhynchonella daleidensis* Kayser, *Abh. k. preuss. geol. Landesanst.*, N.F., Heft i, p. 43, t. v, figs. 2, 3.
 1909. *Rhynchonella daleidensis* Gurich, *Die Leitfossilien*, Lief. 2, Devon, p. 146, t. xlv, fig. 6.

There is a considerable range of variation in this species, and its separation from *Rh. livonica* von Buch, has not always been recognized, but it lacks the parietal ribs on the sinus and on the saddle, which are present in that species. Kayser⁵ remarks that it much resembles *Rh. nymphe* Barr., but has no lateral excavations on the shoulders of the valves. Drevermann⁶ points out that *Rh. daleidensis* is referable to Hall & Clarke's subgenus *Camarotæchia*. *Rh. hexatoma* Schnur, which Fuchs⁷ describes from the Remscheider Beds, seems hardly separable as a distinct species. The specimens in the Sedgwick Museum were obtained from the Red Beds of the New Cut, but Kayser⁸ recorded it from the cliffs and beach below Kilmore.

Horizons.—(1) Red Beds (Staddon Grits); (2), (3), (4) Meadfoot Beds.

¹ Whidborne, *Quart. Journ. Geol. Soc.*, vol. liii, 1897, p. 455, pl. xxxiii, figs. 3–5.

² Fuchs, *Abh. k. preuss. geol. Landesanst.*, N.F., Heft lviii, 1909, p. 57, t. viii, figs. 17, 18; t. ix, figs. 1–5.

³ Gurich, *Die Leitfossilien*, ser. II, Devon, 1909, p. 130, t. xlii, fig. 10.

⁴ Williams & Breger, *op. cit.*, p. 45, pl. ix, figs. 11, 12, 15, 16, 19; pl. x, figs. 1–3, 5–16, 18–29, 32, 33.

⁵ Kayser, *Abh. geol. spec. Karte Preuss.*, Bd. ii, Heft iv, 1878, p. 142.

⁶ Drevermann, *Palæontographica*, Bd. I, 1904, p. 262.

⁷ Fuchs, *Abh. k. preuss. geol. Landesanst.*, N.F., Heft lviii, 1909, p. 69, t. x, fig. 5.

⁸ Kayser, *Neues Jahrb. f. Min. Geol.*, i, 1889, p. 188.

Localities.—(1) New Cut (S. 17, 31); (2) below Kilmore; (3) South of Hope Farm, new drive to Hope's Nose (M.P.G. 1169, 1175, 1179, 1180 Ussher Coll.).

Rensselæria (Rhenorensselæria) crassicauda Koch.

Kegel¹ has put this species together with *R. strigiceps* F. Roem. into a new subgenus, *Rhenorensselæria*, which he has established on account of the difference in the structure of the hinge apparatus of the brachial valve from the typical American representatives of the genus, which has for its type *R. ovoides* Eaton. The subgeneric separation of this European group of species is reasonable, and the name may be conveniently adopted. Amongst the fossils in the Sedgwick Museum from the Red Beds of the New Cut, Torquay, there is one pedicle-valve which may with some confidence be ascribed to Koch's species *R. crassicauda*, which Fuchs² and Kegel³ have described and figured in some detail. Our specimen measures about 16 mm. in length, and shows the characteristic shape and ribbing.

Horizon.—Red Beds (Staddon Grits).

Locality.—New Cut, Torquay (S. 32).

Rensselæria (Rhenorensselæria) cf. strigiceps F. Roemer.

In the Sedgwick Museum, Cambridge, there is the internal cast of the posterior portion of a brachial valve of a large brachiopod, which shows the peculiar and interesting characters of the typical American representatives of *Rensselæria*, with which Clarke⁴ includes Hall's genus *Amphigenia*,⁵ the difference between them lying only in the fusion or separation of the dental plates, and the presence or absence of a low supporting septum. Our specimen⁶ shows a large massive triangular hinge-plate fused to the inner surface of the brachial valve, but obscurely divided into two halves by a shallow median groove; each half has its face slightly hollowed and from its inner anterior angle arises the slender crural process on each side. Between the bases of the crura, which are close together, the hinge-plate projects as a very short blunt, low, median process or ridge, on each side of which is situated a rather deep pit excavated in the thickness of the shell. The hinge-plate is also traversed by a small median, subcylindrical tunnel (the visceral canal), which arises at the beak, and runs from this point forwards through the substance of the hinge-plate to open into the interior of the shell by means of a funnel-shaped aperture on its thick anterior face. This tunnel seems to become larger and quadrangular in cross-section in its posterior

¹ Kegel, *Abh. k. preuss. geol. Landesanst.*, N.F., Heft lxxvi, 1913, pp. 126–32.

² Fuchs, *Jahrb. k. preuss. geol. Landesanst.*, 1903, p. 44. t. vi, fig. 1.

³ Kegel, *op. cit.*, p. 135, t. vi, figs. 14, 15, and references.

⁴ Clarke, *Mem. New York State. Mus.*, No. 9, pt. i, 1908, p. 165; *ibid.*, pt. ii, 1909, p. 81.

⁵ Hall & Clarke, *Palæont. New York.*, vol. viii, Brach. ii, p. 252.

⁶ Reed, *Journ. Torquay Nat. Hist. Soc.*, vol. ii, No. 6, 1920, p. 341.

half. The dental sockets are long, deep, and tubular, and lie parallel to the hinge-line. From each of the pits in front of the hinge-plate proceeds a narrow, sinuous, linguiform vascular marking, which closely embraces the posterior end and sides of the muscle-scar. The latter itself is distinct, well-marked, elongate-oblong in shape, with straight subparallel edges, and is divided by a narrow linear median ridge proceeding from the hinge-plate between the posterior adductor scars, which are crossed by irregular transverse wrinkles. The anterior adductor scars are not preserved, the anterior part of the shell being broken off and missing. The precise shape of the shell cannot be determined accurately, owing to the distortion of the specimen, but it seems to have been subcircular rather than oval or oblong, and to have been of large size, measuring probably about 70 mm. in width. No impression of the exterior is available to show the nature of the external ornamentation. As Clarke has pointed out, the radial lineation in *Rensselæria* frequently dies out on the posterior part of the shell, so that the surface becomes smooth.

There is a second specimen in the Sedgwick Museum of a somewhat smaller shell of the same type, consisting also of the internal cast of the umbonal region of the brachial valve, but it is less perfect than the one above described. The internal characters of *R. strigiceps* (Roem.) have been recently described by Kegel¹ from an internal cast, and they seem to agree with our specimens, except that the latter have a visceral canal in the hinge-plate as in the American forms. Probably these Torquay specimens belong to a new species, but we cannot base one on these internal casts.

Horizon.—Meadfoot Beds.

Locality.—Kilmorrie, Torquay (S. 82) (S. 83).

Rensselæria (*Trigeria*) *Gaudryi* (Oehlert).

According to Kegel,² who has recently discussed the classification of the various species which have been referred to the genus *Rensselæria*, the species *R. confluentina* Fuchs³ is identical with Oehlert's *Trigeria Gaudryi*,⁴ and the genus *Trigeria* can only be regarded as a subgenus of *Rensselæria*. It may be suspected that Davidson's *R. ? striatissima*,⁵ from the Middle ? Devonian of Hope's Nose, and possibly also his so-called variety of ⁶ *R. strigiceps* Roem. from the Middle ? Devonian of Hagginton Hill, Ilfracombe,

¹ Kegel, *Abh. k. preuss. geol. Landesanst.*, N.F., Heft lxxvi, 1913, pp. 126, 127, text-fig. 3; p. 136, t. vi, figs. 16, 17.

² Kegel, *Abh. k. preuss. geol. Landesanst.*, N.F., Heft lxxvi, 1913, pp. 121–31.

³ Fuchs, *Jahrb. k. preuss. geol. Landesanst.*, Bd. xxiv, 1907, p. 50, t. vii, figs. 7–14; t. viii, figs. 1–14; id., *Abh. k. preuss. geol. Landesanst.* N.F., Heft lvi, 1909, p. 73.

⁴ Oehlert, *Bull. Soc. Geol. France*, ser. III, vol. v, 1877, p. 593, pl. x, fig. 8; id., *Bull. Soc. Etudes Sci. Angers*, 1885, p. 2, figs. 10–17. Walther, *Neues Jahrb. f. Min. Geol.*, Beil. Bd. xvii, 1903, p. 57, fig. 1.

⁵ Davidson, *Mon. Brit. Dev. Brach.*, Suppl. v, 1882, p. 19, pl. i, figs. 20, 20a.

⁶ Davidson, id., vol. iii, 1864, p. 10, pl. iv, figs. 5–7.

belong to the same species. In the Sedgwick Museum there is a fairly complete, though crushed and distorted internal cast of a specimen from the New Cut, Torquay, which may without doubt be referred to Fuchs' *R. confluentina*; it possesses about fifty fine low, rounded, simple ribs on the surface, crossed by delicate concentric striæ, and shows the curved dental plates and median septum in the interior, and in its shape and other characters agrees with the specific definition.

Horizon.—Red Beds (Staddon Grits).

Locality.—New Cut, Torquay (S. 19).

Renssælæria (Trigeria) Guerangeri (De Verneuil).

1850. *Terebratula Guerangeri* De Verneuil, *Bull. Soc. géol. France*, ser. I, vol. vii, p. 780.
 1869. *Rhynchonella Guerangeri* De Verneuil in Tschischkoff's "Asie Mineure", *Appendice à la Faune dévon. du Bosphore*, p. 35, pl. xxi, fig. 4.
 1878. *Trigeria Guerangeri* Bayle, *Explic. Carte géol. France*, Atlas, pl. xii, figs. 9-12.
 1883. *Terebratula (Centronella) Guerangeri*, Oehlert, *Bull. Soc. Études Sci. d'Angers*, p. 1, pl. i, figs. 1-11; pl. ii, figs. 1-6.
 1889. *Centronella Guerangeri* Kayser, *Zeitschr. deut. geol. Gesell.*, Bd. xli, p. 294, t. xiv, figs. 3-7.
 1894. *Trigeria Guerangeri* Hall & Clarke, *Palæont. New York*, vol. viii, Brach. ii, p. 272, text-fig. 189.
 1900. *Centronella Guerangeri* Kayser in Toulas' "Geol. Reise nach Kleinasien", *Beitr. Palæont. Geol. Oesterr. Ungarns u. d. Orients*, xii, Heft i, 1899, p. 37.
 1920. *Trigeria Guerangeri* Reed, *Journ. Torquay Nat. Hist. Soc.*, vol. ii, No. 6, pp. 340, 341.

In the Torquay Museum there are certain small, indifferently preserved casts and impressions of a shell from the Staddon Grits, south-west of Brixham, averaging 10 mm. in length, which are apparently referable to this species, and especially resemble Kayser's figures. The Lower Devonian shell described by Fuchs¹ as *Centronella taunica* is closely allied to *R. guerangeri*, according to Kegel,² and may, therefore, also be compared with our specimens.

Horizon.—Red Beds (Staddon Grits).

Localities.—East of the Dart, south-west of Brixham (T. $\frac{2}{6}^0$, $\frac{1}{6}^2$, $\frac{1}{2}^8$); Downton, near Dartmouth (T. $\frac{1}{2}^7$).

Newberria cf. *Deshayesi* (Caillaud).

1861. *Terebratula Deshayesi* Caillaud, *Bull. Soc. Geol. France*, ser. III, vol. xviii, 1861, p. 333, figs. A, B.
 1878. *Meganteris*, sp. Kayser, *Alt. Fauna d. Harzes*, p. 141, t. xxviii, figs. 1-3.
 1889. *Megalanteris Deshayesi* Barrois, *Faune Calc. d'Erbray*, *Mem. Soc. Geol. Nord.*, iii, p. 151, pl. x, fig. 6a, b.

The internal cast of the greater part of a brachial valve from Kilmorie, which is in the Sedgwick Museum, shows characters which

¹ Fuchs, *Jahrb. k. preuss. geol. Landesanst.*, xxxiii, ser. II, Heft 1, 1912, p. 62, t. v, figs. 5-8.

² Kegel, *Abh. k. preuss. geol. Landesanst.*, N.F., Heft lxxvi, 1913, pp. 132, 139.

indicate its reference to Hall's genus, *Newberria*,¹ of which the type is *Rensselaeria ? johannis* Hall.² Our shell may be compared with *N. deshayesi* (Caillaud) from the European Lower Devonian, and it shows well the elongate subovate adductor scars divided by a thin ridge (as in Caillaud's figure), and the very narrow submarginal dental sockets which Hall & Clarke illustrate (op. cit. pl. lxxviii, fig. 11) in *N. johannis*. Gürich³ adopts the name *Newberria* for the two European species, *Terebratula caiqua* D'Arch & Vern. and *T. amygdala* Goldf., but he does not mention *T. deshayesi* Caill. or *Meganteris inornata* D'Orb., both of which Hall & Clarke (op. cit. pp. 264, 281) consider are referable to *Newberria*. *Dielasma rhenana* Drevermann⁴ may also belong to this genus.

Horizon.—Meadfoot Beds.

Locality.—Kilmorie (S. 67a).

Tropidoleptus rhenanus Frech.

1853. *Leptaena laticosta* Schnur, *Palæontographica*, Bd. iii, p. 220, t. xl, fig. 2.
 1864. *Leptaena* or *Orthis laticosta* ? (Conrad), Davidson, *Mon. Brit. Dev. Foss.*, vol. iii, p. 87, pl. xvii, figs. 1-3.
 1882 ? *Rhynchonella laticosta* Etheridge, *GEOL. MAG.*, Dec. II, Vol. IX, p. 156, Pl. IV, Fig. 7.
 1897-1902. *Tropidoleptus rhenanus* Frech, *Lethæa Geogn.*, Bd. ii, Lief. i, p. 143, footnote 1.
 1902. *Tropidoleptus carinatus* var. *rhenana* Drevermann, *Palæontographica*, Bd. xlix, p. 99, t. xii, figs. 11, 12.
 1913. *Tropidoleptus carinatus* Kegel, *Abh. k. preuss. geol. Landesanst.*, N.F., Heft lxxvi, p. 104.

Davidson's figures of the British examples do not show the decrease in the strength and distinctness of the lateral ribs, which is a characteristic feature, and is well seen in specimens in the Jermyn Street Museum. The number of the ribs varies, and according to Drevermann (op. cit.) is of little importance, and there is a considerable range of variation in the closely allied or scarcely separable American species (*Tr. carinatus* Conr.), from the Hamilton Formation.⁵ It is probable that Etheridge's *Rhynch. laticosta* Dav., from Smugglers' Cove, should be referred to *Tr. rhenanus*, for it seems to possess the typical characters. Upfield Green⁶ has recorded it from the "Gedinnian" of Cornwall, and Davidson had previously given Looe as a locality for its occurrence. It seems to be fairly common in the Meadfoot Beds, but crushed specimens of *Ch. plebeia* have often been mistaken for it, and are difficult to distinguish.

Horizon.—(1) Meadfoot Beds; (2) "Lower Devonian".

¹ Hall, *10th Ann. Rep. New York State Geol.*, 1891, pp. 91-9, pls. v, vi.

² Hall & Clarke, *Palæont. New York*, vol. viii, Brach. ii, pp. 261, 281, pl. lxxviii, figs. 10-16.

³ Gürich, *Die Leitfossilien*, Lief. ii, Devon, 1909, p. 148.

⁴ Drevermann, *Palæontographica*, Bd. xlix, 1902, p. 98, t. xii, figs. 7-10.

⁵ H. S. Williams, Prof. Paper 79, *U.S. Geol. Surv.*, 1913, pp. 36-42, pls. i, ii.

⁶ Upfield Green, *GEOL. MAG.*, Dec. V, Vol. I, 1904, p. 406.

Localities.—(1) Meadfoot (S. 35, 29); "Torquay" M.P.G. $\frac{2}{2}$ i, $\frac{2}{2}$ i, $\frac{2}{2}$ o pass); (2) Smugglers' Cove (? Etheridge's *Rh. laticosta*); Beach, south of Smugglers' Cove (M.P.G. 1188 Ussher Coll.); south of Hope Farm, edge of Bramblebrake (M.P.G. 1176, 1182, 1181 Ussher Coll.); field south of Oxlea Hill (M.P.G. 1218, 1219 Ussher Coll.); Windmill Hill, south of Paignton (M.P.G. 1223 Ussher Coll.).

Spirifer subcuspidatus Schnur.

The commonest species of *Spirifer*, occurring in the Kilmorie beds, may be referred to *Sp. subcuspidatus* Schnur,¹ or to one of its varieties, as interpreted by Fuchs.² None of the Torquay specimens are well preserved, but the internal casts and external impressions, both of which are usually fragmentary or distorted, are sufficient to identify them with this species rather than with the allied *Sp. hystericus* Schloth,³ *Sp. carinatus* Schnur,⁴ *Sp. incertus* Fuchs,⁵ and *Sp. crassifulcitus* Spriesterb.⁶ The points of distinction between these species is by no means a matter of agreement amongst Continental palæontologists, but *Sp. cuspidatus* apparently differs from *Sp. hystericus* chiefly by its more numerous ribs. R. and E. Richter⁷ have recently revised the members of the group of *Spirifer subcuspidatus* and introduced several new specific names, but our poor material does not admit of such precise differentiation.

Horizon.—Meadfoot Beds.

Locality.—Kilmorie (S. 34, 45, 54, 55).

Spirifer mediorhenanus Fuchs?

1909. *Spirifer mediorhenanus* Fuchs, *Abhandl. k. preuss. geol. Landesanst.*, N.F., Heft lviii, p. 67, figs. 1-6.

1915. *Spirifer mediorhenanus* Fuchs, *ibid.*, Heft lxxix, p. 25, t. vi, figs. 6-20.

1920. *Spirifer arduennensis*?, Reed, *Journ. Torquay Nat. Hist. Soc.*, vol. ii, No. 6, p. 339.

The one impression of a brachial valve from Kilmorie, which was previously referred by me (*op. cit. supra*) with a query to Schnur's species *Sp. arduennensis*, seems now to be better placed in Fuchs' species *Sp. mediorhenanus*, judging from his figures and description. Our specimen has the transverse shape and pointed angles of his shell, and the six or seven broad, slightly subangular closely placed ribs on each lateral lobe; the low, rounded median saddle is somewhat flattened, and expands rather rapidly in width to the front

¹ Scupin, *Palæont. Abhandl.*, viii, 1900, p. 19, t. i, figs. 13, 14.

² Fuchs, *Abh. k. preuss. geol. Landesanst.*, N.F., Heft lviii, 1909, pp. 60-3, t. ix, figs. 11-15.

³ Drevermann, *Palæontographica*, Bd. l, 1904, p. 253, t. xxx, figs. 15-19; Scupin, *op. cit.*, p. 12, t. i, figs. 3-5.

⁴ Scupin, *op. cit.*, p. 26.

⁵ Fuchs, *Abh. k. preuss. geol. Landesanst.*, N.F., Heft lxxix, 1915, p. 24, t. vi, figs. 2-5.

⁶ Spriesterbach, *ibid.*, N.F., Heft lxxx, 1915, p. 7, t. ii, 5-8; t. iii, figs. 1-9.

⁷ R. and E. Richter, *Jahrb. Nassau. Vereins f. Naturk.*, Jahrg. 72, 1920, pp. 26-38.

margin, where it equals about three lateral ribs. The concentric growth-ridges are conspicuous on the whole surface of the valve.

Horizon.—Meadfoot Beds.

Locality.—Kilmorie (S. 60).

Spirifer parcefurcatus Spriesterbach ?

1915. *Spirifer parcefurcatus* Spriesterbach, *Abh. k. preuss. geol. Landesanst.*, N.F., Heft lxxx, p. 16, t. iv, figs. 7-14; t. v, figs. 1-3.

1920. *Spirifer Bischofi* ? Reed, *Journ. Torquay Nat. Hist. Soc.*, vol. ii, No. 6, pp. 340, 342.

This species is closely allied to *Sp. bischofi* A. Roem.,¹ to which an example from Smugglers' Cove is an imperfect condition has been previously referred by me. But according to Spriesterbach (op. cit.) it differs in the ribbing of the fold and sinus. Scupin² included this form in *Sp. bischofi*, and Drevermann³ has also discussed the variable characters of the latter species and its relation to other species. It is almost certain that the shell from Lynton, figured by Whidborne⁴ as *Sp. daleidensis* Stein., which is a closely allied form, should be referred to *Sp. parcefurcatus* or to *Sp. bischofi*.

Horizon.—Red Beds (Staddon Grits).

Locality.—Smugglers' Cove (S. 57).

Spirifer decheni Kayser ?

In the Whidborne collection of fossils from Meadfoot in the Sedgwick Museum there is a crushed and distorted specimen, 35-40 mm. in length and rather more in width, which shows the external impression and internal cast of a large species of *Spirifer*, and is apparently referable to *Sp. decheni* Kayser,⁵ which Scupin⁶ and Assmann⁷ consider identical with *Sp. fallax* Giebel,⁸ and closely allied to *Sp. primævus*. Our shell specially resembles Oehlert's⁹ and Barrois'¹⁰ figure of *Sp. decheni*, and is subrhomboidal in shape with 10-12 coarse angular ribs on each side of a broad angular sinus in the pedicle valve.

Horizon.—Meadfoot Beds.

Locality.—Meadfoot (S. 80).

¹ A. Roemer (Giebel), *Silur. Fauna Unterharz.*, 1858, p. 29, t. iv, fig. 3.

² Scupin, *Palæont. Abhandl.*, Bd. iii, 1900, p. 73, t. vii, figs. 1-3.

³ Drevermann, *Palæontographica*, Bd. l, 1904, p. 252, t. xxix, figs. 15-17.

⁴ Whidborne, *GEOL. MAG.*, Dec. IV, Vol. VIII, 1901, p. 531, Pl. XVII, Fig. 6.

⁵ Kayser, *Abh. geol. specialK. Preuss.*, Bd. ii, Heft iv, 1878, p. 165, t. xxii, figs. 1, 2.

⁶ Scupin, op. cit., p. 85.

⁷ Assmann, *Jahrb. k. preuss. geol. Landesanst.*, 1910, Bd. xxxi, Heft i, p. 138, t. vi, figs. 5-11.

⁸ A. Roemer (Giebel), *Silur. Fauna Unterharz.*, 1858, p. 32, t. iv, fig. 1.

⁹ Oehlert, *Bull. Soc. Geol. France*, ser. 3, vol. xvii, 1889, p. 779, pl. xxi, fig. 3.

¹⁰ Barrois, *Faune Calc. d'Erbray*, *Mem. Soc. Geol. Nord*, iii, 1889, p. 127 pl. viii, figs. 1, 1a-f.

Athyris [*Spirigera*] *undata* (Defrance).

1828. *Terebratula undata* Defrance, *Dict. sciences nat.*, vol. liii, p. 155.
 ? 1853 *Terebratula sculpta* Steininger, *Geogr. Besch. Eifel.*, p. 68, t. vi, figs. 15, 16; t. xxix, fig. 7.
 1855. *Terebratula undata* De Verneuil, *Bull. Soc. Geol. France*, ser. II, vol. xii, p. 1008, pl. xxix, fig. 7.
 1855. *Spirigera undata* Sandberger, *Sitzungsber. k. k. Akad. Wiss. Wien*, Kl. Nat., Bd. xviii, p. 116, t. i, figs. 10, 11.
 1878. *Athyris undata* Bayle, *Explic. Carte geol. France*, Atlas, pl. xii, figs. 1-14.
 1885. *Athyris undata* Oehlert, *Ann. Sc. géol.* xix, art. 1, p. 32, pl. iii, fig. 1-20.
 1889. *Athyris undata* Kayser, *Abh. k. preuss. geol. Landesanst.*, N.F., i, p. 38, t. iii, figs. 1-6; t. i., fig. 1; t. xvii, figs. 1, 2.
 1915. *Spirigera undata* Fuchs, *Abh. k. preuss. geol. Landesanst.*, N.F., Heft lxxix, p. 27, t. vii, figs. 4-7.

Good internal casts showing all the characteristic features of this species occur in the Kilmorie Beds, some of which show the muscle-scars extremely well. One specimen has a length of 32 mm. and a width of 44 mm. Upfield Green¹ has recorded this species from the Gedinnian of Cornwall. The species is restricted to the Lower Devonian.² The species *A. avirostris* Krantz,³ is scarcely separable from it, and the same may be said of *A. rauffi* Assmann.⁴

Horizon.—Meadfoot Beds.

Locality.—Kilmorie (S. 33, 44, 50).

Note.—Since the publication of Part I of these Notes on the Fauna of the Lower Devonian Beds of Torquay (GEOL. MAG., Vol. LVII, 1920, pp. 299-306, 341-7, Pl. IV) my attention has been drawn to the fact that after an examination of the types Rudolf Richter (*Jahrb. k. preuss. geol. Landesanst.*, Bd. xxxvii, i, Heft 2, 1916, pp. 250-2, t. xxv, xxvi) has been led to consider that the original *Cryphæus laciniatus* F. Roemer is a synonym for *Cr. rotundifrons* Emmrich, and that Kayser's *Cr. Lethææ* is divisible into two distinct species, *Cr. Lethææ* sens. str. and a new one *Cr. Kochi* Richter (op. cit., t. xxv, figs. 6-9; t. xxvi, figs. 1-6).—F. R. C. R., May, 1921.

An Outline of Chinese Geology.

By J. S. LEE, M.Sc., Birmingham.

(Continued from p. 265.)

(WITH PLATE VI.)

THE WUTAI-NANKOU SYSTEMS.

WHEN Richthofen journeyed in the Wutai district, Shan-si, he found a mighty sequence of metamorphosed sedimentary strata⁵ which could not be classed as his Sinian or any series

¹ Upfield Green, GEOL. MAG., Dec. V, Vol. I, 1904, p. 406.

² Béclard, *Bul. Soc. belge Geol. Pal. Hydr.*, vol. i, 1887, p. 83.

³ Drevermann, *Palæontographica*, Bd. 1, 1904, p. 256, t. xxx, figs. 13-18.

⁴ Assmann, *Jahrb. k. preuss. geol. Landesanst.*, xxxi, i, 1910, p. 153, t. xi, figs. 1-5.

⁵ *China*, vol. ii, p. 367.

younger than the Sinian, nor could it be regarded as belonging to the Old Gneiss and Gneiss-granite group. They are apparently equivalent to similar strata occurring in eastern Shan-tung and Liao-tung.¹ In descending the Wutai-shan along its southern flank, Richthofen first came across a thick series of green schists with alternating beds of grey slates and quartzites, and then several series of coarse quartzitic and felspathic well-stratified rocks, aggregating to a thickness of more than 5,900 feet. He calls the whole sequence of these strata the "Wutai Formation", and parallels it with the Huronian. This term at once found a wide application in Chinese geology. Thus in the western Tsing-ling Range, south of Lio-yang-hsien (about long. 106° E., lat. 33° 25' N.), and in the high mountains west of Ta-tsien-lu (about long. 102° 10' E., lat. 30° N.), Loczy distinguishes a series of highly metamorphosed sedimentary rocks, such as gneiss, schists, phyllites, crystalline limestone, etc.,² and assigns it to the Wutai Formation. The "Nan-shan Sandstone"—a series of unfossiliferous grey and green sandstones with well-cleaved or even schistose clayslates, typically developed in the northern foothills of the Nan-shan Ranges—is also tentatively regarded by the same author as a Wutai Formation. Between Ping-liang and Men-chou, in the province of Kan-su, Futterer identified in several places the Nan-shan Sandstone, and found other metamorphosed sedimentary strata of the Wutai Formation, consisting of chlorite-schist, coarse-grained quartzite, slate, and graywacke. In all these cases the term Wutai evidently implies the analogy with the Algonkian of North America.

As the result of field observations in the adjoining area of Shan-si and Chi-li,³ particularly in the Wutai district, Willis and Blackwelder were able to recognize two systems of rocks of pre-Cambrian age: the lower or the Wutai System rests unconformably upon the Tai-shan Complex, and the upper or the Nankou (Huto) System is believed by the same authors to overlie unconformably the Wutai System. They further state that the unconformable junction between the Huto and the Wutai may be seen on the top of the Nantai-shan. This statement has been, however, not yet confirmed by published reports of field observation in the Wutai district. What may be regarded as a case supporting this inferred stratigraphical relation is a photograph in the *Record of the Work of the Geological Institute*, showing the Nankou (Huto) System resting unconformably on the Wutai strata in the Chien-an district, north-eastern Chi-li.

The Wutai System is well developed in the south-eastern flank of the Wutai-shan. Willis and Blackwelder divide it into three series in the following descending order:—

¹ *China*, vol. ii, pp. 106, 107, 215-17.

² Loczy, op. cit., vol. i, pp. 428-65, 692-726.

³ Willis, op. cit., vol. i, pt. i, pp. 99-135.

- c. Sitai Series. A thick series of monotonous, fine-grained chlorite-schists grading downwards into a basal conglomerate, which latter contains such pebbles "as the underlying Nantai Series would furnish".
- b. Nantai Series. Largely consists of dark quartzite and siliceous marble with a subordinate amount of schist; the total thickness is probably less than 2,000 feet.
- a. Shitsui Series. Stratified schists, gneiss, and schistose quartzite predominate in this series. The apparent thickness is estimated at 12,000 feet; but the real thickness may not be more than 6,500 feet.

According to Willis and Blackwelder, the Huto System is exposed in the Tou-tsun, Liu-yuan, Tung-yu districts, near the Wutai-shan, and in the northern slope of the Ki-chou-shan (about long. 113° E., lat. $38^{\circ} 30'$ N.). It consists of two series:—

Upper. Tung-yu Limestone. Limestones with subordinate slates; the former sometimes contain beds of quartzite, and sometimes layers of flints; total thickness 3,500–5,000 feet.

Lower. Tou-tsun Slate. Grey phyllite or slate with occasional thin layers of limestone or dolomite; total thickness 3,000 feet or more.

In the same area the above-mentioned authors distinguish a third formation of limestone, the Ta-yang Limestone, containing numerous characteristic layers of flints and occasional beds of quartzite. With good reason they assign the Ta-yang Limestone to the Nankou (Huto) System. From lithological similarity and from the parallelism of stratigraphical sequence, Willis correlates the Ta-yang Limestone and other Huto rocks with the series of flinty limestone of Nankou, north-western Chi-li, and of the Hwei-lu district, south-western Chi-li, that underlies the fossiliferous Cambrian. He therefore proposes to replace the term Huto System by the term Nankou System when the equivalency of the two is eventually established.

Although rocks of approximate Algonkian age in Chi-li and north-eastern Shan-si permit of a twofold grouping the application of this classification outside this area is problematical. Pending further research, a collective name would be useful for denoting those rocks found in all parts of China that are equivalent to a part or the whole of the Wutai and the Nankou (Huto) Systems. For this purpose we may conveniently use a united term, the Wutai-Nankou Systems.

The Wutai-Nankou Systems thus defined would include, in addition to the rocks so far mentioned, the chlorite-schist, biotite-schist, crystalline limestone, slates, quartzite, and other highly altered sedimentary strata in the eastern and middle Tsing-ling Range; a part of the highly metamorphosed strata in the north-western Nan-shan Ranges, namely, on the southern side of the Tolai-shan, in the Da-ssue-shan, the Ritter Mountain, and the Muschketov Range; the "pre-Cambrian" quartzite and quartzose phyllite with green grits exposed between Kwei-lin and the Si-kiang, in the province of Kwei-chou, and other "pre-Cambrian" rocks that occur to the west of Kien-kiang, in the

vicinity of Ta-li (Yun-nan), and in the "Zone of Hou-kouang Flexure" (Kwang-si)¹; the crystalline phyllite observed by Mr. V. K. Ting in the Tehu-ning district, Yun-nan. The quartz-rock exposed in the neighbourhood of Hong-kong, the schist that occurs in association with granite in the Isle of Hai-nan,² and finally the Kao-liang Series³ of the Teng-yue district as mentioned by J. C. Brown, should perhaps be attributed to these Systems.

As will be seen from the above sketch, China, particularly Northern China, is one of the few countries that offer good opportunity for the study of pre-Cambrian geology. Unfortunately, neither the scope of this paper nor the state of our present knowledge permit us to discuss the geological processes that were operative as the earliest geological era dawned in that part of the globe; and any such attempt would inevitably involve us in the old conflicts between different schools of uniformitarians. That the basal stratum of the Wutai System was originally formed under water is, however, an unquestionable fact. The Wutai Sea, which presumably covered parts of north-east China during the early stage of the Wutai period, became fairly deep towards the middle of the same period, or the Nantai epoch. During the latter part of the Wutai period, or the Sitai epoch, a wide ocean extended over large areas of northern China, and received strikingly uniform clayey material from all the surrounding lands. Even the northern Tsing-ling area that had evidently stood above the Nantai water, was by this time submerged under the Sitai sea; as evidence Richthofen and Willis have independently and definitely identified the chlorite-schist of the Sitai Series in the eastern and the middle Tsing-ling Range.

An orogenic movement of far-reaching character took place in Northern China at the end of the Wutai period. The rocks formed during the Wutai period were thus severely deformed and dynamically metamorphosed. Large bosses of granite and syenite with their accompanying offshoots and differentiated dykes, were injected into the Tai-shan Complex and the Wutai strata, such as those found in eastern Shan-tung, north-eastern Shan-si, and western Hu-peh. The advanced phase of metamorphism usually exhibited by the Wutai rocks in contra-distinction to the slightly altered state of the overlying Nankou or Huto Formation, speaks for the intensity of the stress and strain that the Wutai rocks must have gone through before the formation of the Nankou rocks had begun. The principal attack of the movement seems to have come from the south-east, for it has impressed a north-easterly strike on the rocks affected.

As this great disturbance gradually died out, the area of Shan-si and Chi-li began to subside. The Nankou period thus set in. If

¹ Leclère, *op. cit.*, pp. 21-2.

² Madrolle, "Étude sur l'isle d'Hainan": *Bull. Soc. géogr. Paris*, sér. VII, vol. xix, pp. 187-228.

³ *Record Geol. Surv. India*, vol. xliii, p. 188, pl. iii.

the chemical composition of the pre-Cambrian rocks signifies certain physical conditions of the sea in which they were formed in such a way as it does in the case of post-Cambrian deposits, then we may take the fact that the Nankou Formation changes its lithological character from argillaceous to calcareous towards its upper part in the area of Chi-li and Shan-si, as being indicative of a persistent lowering of the sea-floor. Nevertheless, in western Shan-tung, apart from the occasional presence of a few thin beds of a flinty limestone, which may be doubtfully regarded as the latest stage of the Nankou Formation, we know no rocks equivalent to the Nankou System of Chi-li. What are supposed to be the representatives of the Wutai System there are schists and quartzites which nowhere attain a great thickness, and are frequently absent. These facts converge to show that practically during the whole of the Nankou period western Shan-tung was subjected to subaerial denudation. The Tsing-ling area is likewise reported to be free from sediment belonging to the Nankou System.

The continued subsidence of the sea-floor in Chi-li and Shan-si appears to have been accompanied by a gradual and uniform elevation of the neighbouring lands, enabling the eroding agencies to reduce north-east China to a vast peneplain of mature type. Elsewhere towards the close of the Nankou period the tranquil sedimentation was, however, punctuated by local earth movements. In the Tsing-ling area this movement may have reached to the magnitude of an orogenic upheaval. Igneous magma again intruded itself at several localities in northern China. They are essentially of basic composition, and relatively insignificant in number.

THE SINIAN OR CAMBRO-ORDOVICIAN.

The term Sinian was first introduced by Pumpelly for expressing a system of north-east folds in Eastern Asia.¹ Richthofen during his exploration found a group of rocks, chiefly composed of limestones, spreading over large areas in north-east China where the Sinian folds prevail. He then termed the rocks the Sinian (Sinisch) Formation. The discovery of a "primordial fauna"² in the middle part of this mighty sequence of rocks led Richthofen to believe that the top of the Sinian chronologically extended into the Ordovician, and its base reached down, in some cases, to the pre-Cambrian.

An unconformity of great magnitude was subsequently discovered by Willis and Blackwelder within the Sinian System of Richthofen. The plane of the unconformity lies directly below a series of red shale and sandstone. They therefore found it desirable to shift the lower boundary of the Sinian System on to the plane of the said unconformity. The lower part of Richthofen's Sinian System, namely, the series of strata lying underneath the fossiliferous red

¹ Pumpelly, "Geological Researches in China, Japan, and Mongolia": *Smithsonian Contributions*, vol. xv, p. 67.

² Dames, *China*, vol. iv, pp. 1-33.

A SKETCH-MAP OF
CHINA
SHOWING ITS
TECTONIC OUTLINES.

References:-

Strike of cleavage-
plane and trend of
fold or flexure.

Fault or fracture.

Uncertain fault or
fracture.

Provincial boundary.



series, is accordingly assigned to the older systems. It should be noted, however, that in the Nankou area, north-western Chi-li, the Nankou limestone appears to pass upwards into the Sinian without a notable break.¹ The upper boundary of the Sinian System is likewise well defined by a stratigraphical break of considerable vertical range and horizontal extent. Immediately above this plane of unconformity lies the coal-bearing Shansian System.

Throughout north-east China, namely, the area comprising the provinces of Shan-tung, Chi-li, Shan-si, and Ho-nan, the development of the Sinian System is wonderfully similar in lithology as well as in faunal record. Nowhere within the above-described area do the succession and the character of the three principal series of the Sinian differ to any extent from the following generalized section in descending order:—

- c. *Orthoceras* Limestone. A massive, uniform limestone often dolomitic; containing few fossils excepting in one zone near the top of the series where whole beds are formed by *Orthoceras* and *Actinoceras*. *Asaphus*, *Maclurea*, and other Ordovician forms are rarely found.

The Tsinan Limestone of western Shan-tung and the upper Kichou Limestone of north-eastern Shan-si are local representatives of this series.

- b. Globulitic Limestone. Series of peculiar oolitic, globulitic, or even pseudo-conglomeratic limestones with occasional intercalations of shale; crowded with Upper and Middle Cambrian fossils, particularly trilobitic remains; *Ptychaspis*, *Tsinania*, *Conocephalina*, *Anomocare*, *Anomocarella*, *Dorypyge*, *Ptychoparia*, *Drepanura*, *Agnostus*, etc., are among the well-known genera.¹

In Liao-tung and western Shan-tung Richthofen names the upper part of this limestone the Lung-mönn Series and the lower part the Tung-wönn Series; Blackwelder calls them the Kiu-lung Group. In Shan-si it is represented by the lower part of the Kichou Limestone.

- a. Manto Shale. Red and brown shales with subordinate sandstones and earthy limestones containing the characteristic species *Redlichia chinensis*, a form resembling *Olenellus*.

¹ *China*, vol. ii, p. 306.

(To be concluded.)

REVIEWS.

ECONOMIC MINERALOGY. By THOMAS CROOK, A.R.C.S., F.G.S., M.I.M.M. pp. xi + 492, with 247 figures. London : Longmans, Green & Co., 1921. 25s. net.

AS the author states in the preface this volume is intended for those especially interested in the utilitarian side of mineralogy, he therefore contents himself with one chapter on crystal symmetry instead of the usual detailed account of all possible crystal forms given in textbooks of mineralogy. As the economic mineralogist seldom meets with well-crystallized minerals, the writer thinks this is a justifiable curtailment.

The chapter on crystal optics is an unusually clear exposition of what is often a difficult subject to the student of mineralogy, and the same applies to the chapter on physical analysis, but the section dealing with flotation might have been improved if a simple apparatus for laboratory separation by flotation had been described.

Under the geology of mineral deposits the author gives a useful summary of the chief deposits of economic minerals arranged in order of age.

The detailed description of the individual minerals is clear and complete, and the lists of the chief occurrences of the minerals of each metal are much more complete and detailed than is usual.

In the description of the use of the Westphal balance, no details are given of the use of the instrument for the determination of the specific gravity of a mineral fragment, nor is there any mention of the use of the hydrometer for the determination of the density of a liquid which is certainly not often made use of in mineralogical work.

At the end of the volume is a series of tables, the first of which gives the minerals in order of hardness with their chief physical and chemical properties, and with the refractive index and birefringence of the minerals with non-metallic lustre. It would have been useful to add these last details in the case of the minerals with metallic lustre which are transparent under the microscope.

The last table gives the minerals grouped according to colour, but the fact of there being only six colour groups seriously affects its value as a help to determination.

The illustrations are excellent, the photographs in most cases being taken from specimens in the Natural History Museum.

E. H. DAVISON.

CHROMIUM ORE. By W. G. RUMBOLD. Imperial Institute Monographs on Mineral Resources. 58 pp., with 2 diagrams and a map. London : John Murray, 1921. Price 3s. 6d. net.

THE importance of chromium in the metallurgy of steel and the wide use of certain of its compounds in technology, have long been known, and the recent introduction of alloys of the stellite group

appears to offer a further field of usefulness. For some years past Southern Rhodesia and New Caledonia have been the largest producers, but war conditions led to a reversion by the Central Powers to old sources of supply in Asia Minor, while enormous development took place in the low-grade ores of the United States. This monograph contains a very complete account of the geological occurrence and exploitation of chromite, the only practicable ore of the metal, together with a summary of its technical treatment and uses. The employment of chromite as a refractory seems likely to extend in the future. The work follows the general plan of this now well-known series and includes useful tables and a bibliography.

THE LIFE OF HORACE BENEDICT DE SAUSSURE. By DOUGLAS W. FRESHFIELD, D.C.L., with the collaboration of HENRY F. MONTAGNIER. London: E. Arnold, 1920.

A REALLY good life of De Saussure in English has long been desired, and no one so competent as Dr. Freshfield could be found to undertake it. He began Alpine travel with his parents as a boy of 14, and after graduating at Oxford, visited Syria and Armenia, nearly reaching the summit of Ararat; climbed Kasbek and a peak of Elbruz; went over high passes and ascended peaks in the Caucasus; took a high-level route round Kanchenjunga; has visited mountain lands in Uganda and elsewhere, and can describe them admirably, as his many books show; and recently, through Mr. Montagnier, he has obtained access to many letters by De Saussure which were previously unknown. He has in short given us a singularly interesting book on a great pioneer in Alpine travel, and a man in other respects remarkable. De Saussure was born in 1740, a citizen of Geneva, a member of a rather wealthy family, and an exceptionally able man. Educated at the College and University of his native city, he paid his first visit to Chamonix in 1760, the glaciers of which, though Mont Blanc is in full view, may be said to have been discovered nineteen years earlier by Poccocke and Windham, was appointed Professor of Physics and Metaphysics in 1763, discharged these rather opposite tasks with success; married two years later a wife who added much to his happiness and property, and in 1768 began a two years' journey in France, Holland, and Britain, during which he made many friends and was hospitably entertained by such men as Sir Joseph Banks and Lord Palmerston, father of the one better known; visited Stamford and Burghley, York, Knaresborough, Leeds—where he went down a coal-mine, Wynnstay, Wentworth Castle, Chatsworth, Manchester, caverns and mines in Derbyshire, and even travelled to Cornwall to inspect its mines, recrossing the Channel in the beginning of 1769. He had also visited the two Universities, met numerous men of eminence, and been welcomed everywhere.

But his records of his journeys, both at home and abroad, are unfortunately incomplete. His last Alpine journey was in 1792,

the concluding volume of the voyage four years' later. By this time his health had failed. Notwithstanding his efforts, he had been carried into the political vortex, of which Geneva was a centre, and forced to take a leading part in politics. It was an epoch of revolutionary ferocity, such as that of which we have not yet seen the end. De Saussure was almost ruined, and his life more than once in imminent danger. Then he became an official, but a new evil was at hand. Early in 1794 he had a stroke of paralysis, after which his journeys were restricted to those in search of health. Two years afterwards the anarchists again broke loose, after which, notwithstanding the promises of Napoleon, Geneva became the *chef lieu* of a French Department. De Saussure did not long survive the Republic, which he had done his best to raise, for he passed away peacefully in his town house on 22nd January, 1799.

Except for a dyspeptic tendency, his health was good, he was capable of much endurance, and his intellectual vigour was remarkable. Repeatedly he anticipated the conclusion of other workers. The intellectual gap between his writings and those of Scheuchzer is remarkable. The two writers were separated by about half a century, but the *Itinera Alpina* abounds in stories of dragons lurking in caverns, flying through the air, or haunting Alpine recesses, while De Saussure writes as a man of science. On only one important matter does he go wrong. He failed to obtain a sound idea of glacier motion, and attributed moraines and perched blocks to great catastrophes and floods. But, excepting these, which, had health been maintained, he might have corrected, he surpassed all his predecessors, except Leonardo de Vinci.

SUMMARY OF PROGRESS OF THE GEOLOGICAL SURVEY OF GREAT BRITAIN. pp. 70, 3 text-figures. 1919.

IT is highly satisfactory to find that with the return to more normal conditions generally the officers of the Geological Survey have been able to resume the work upon which they were engaged in pre-war days in the Montgomery-Shropshire district and the Warwickshire-Staffordshire district.

In the first of these districts the most interesting work accomplished would appear to be the completion of the mapping of the Ordovician rocks, the adoption of the terms Caradocian and Ashgillian for the upper members of the series, and the recognition of the advent of *Pentamerus* as indicative of the beginning of Silurian. In the Warwickshire-Staffordshire area important work relative to the demarcation of the Middle Coal Measures (Grey Productive Measures) has been carried out.

Notes relative to lead, zinc, and copper mines in various parts of the country are given, and the borings for oil in Derbyshire and Staffordshire are also reported on.

In Scotland the Highland work was resumed in the North and Central Highland district, and the revision of the coalfields continued.

Work in South Lanarkshire has resulted in considerable increase in knowledge concerning the important outlier of the Douglas Coalfield, and a valuable comparison made between the beds at Coalburn and Ponteigh illustrated by clear vertical sections of the rocks worked at the two places. Borings for oil have been made in many places in the coalfields and oil-shale fields, the most interesting being the search for the extension of the Linlithgowshire oil-shales in a north-west direction, without success. The important and interesting details relative to the alternative of these oil-shales are made the subject of a special appendix, illustrated with three admirable vertical sections.

As usual the appendices contain details relative to matters of special economic import; of these which are five in number, three relate to coalfields and two to Mesozoic rocks.

G. L. E.

FOSSIL BIRD-REMAINS COLLECTED BY DR. FORSYTH MAJOR IN SARDINIA, CORSICA, AND GREECE. By E. T. NEWTON. *Proc. Zool. Soc.* April, 1921.

DR. FORSYTH MAJOR has for many years been interested in collecting fossil vertebrate remains from caves in Sardinia and Corsica, and several years ago some interesting bones of birds from among these fossils were described by Mr. R. Lydekker. Since then further extensive explorations in these and several other caves have yielded many more remains of both mammals and birds. We are still waiting for Dr. Forsyth Major's description of the former, but the Avian bones are briefly described in the present paper by E. T. Newton. A few additional species are noted from the three caves which yielded Mr. Lydekker's specimens. Several other caves have also yielded birds' bones, but by far the greater number are from the Grotta di Funtanedu, near Basta, N.E. Corsica, which is said to be 400 metres above the sea. A list of some thirty-four species is given from this cave, but each is represented by only a few bones. All the forms identified are referred with more or less certainty to living species, but a few of them seem not to have been previously recorded from these Mediterranean islands. Although the Avian species recognized give no clue to the geological horizon of the deposits in these caves, Dr. Forsyth Major has reasons for regarding them with one exception as of Pleistocene Age.

REPORTS AND PROCEEDINGS.

GEOLOGISTS' ASSOCIATION.

3rd June, 1921.

"The Geology of Belgium, with special reference to the Long Excursion." By L. Dudley Stamp, M.Sc., A.K.C., F.G.S.

Natural regions and physical geography of the country. The northern lowlands, the long narrow Namur Coalfield, the southern

uplands (Ardennes). Relation of topography to geological structure; the northern lowlands a Palæozoic platform covered by Cretaceous and Tertiary; the Namur Basin a Devono-Carboniferous synclinorium; the Ardennes also a Devono-Carboniferous synclinorium with a Silurian ridge on the north and Cambrian "massifs" on the south. Geological history of the country; pre-Devonian rocks; the great Devonian transgression. The late Carboniferous (Armorican or Hercynian) folding. The Ardennes—London ridge and its influence on Mesozoic and Tertiary stratigraphy. The Cretaceous transgression. The Anglo-Franco-Belgian Basin of Eocene times. Pliocene: Diestian and Lenham Beds. Tectonics — three great epochs of folding; late Silurian, late Carboniferous (Armorican), Cretaceo-Tertiary (Alpine). The Brabant stable block and its influence on Armorican folding. Some notes on the districts to be visited.

"Possible causes of Mountain Folding." By A. J. Bull, M.Sc., F.Inst.P., F.G.S.

Salient features of the earth's crust, the lines of folded mountains bordered by large regions of no compression. Occasional evidence of tension. Fjords. Fissure eruptions.

Explanations of folding by (a) the assumption that the earth is cooling, (b) periodic contraction of the earth due to molecular rearrangement, (c) penetration of oceanic water into the crust, (d) loading of the crust by terrigenous deposits and other hypotheses. Difficulties of accepting some of these explanations.

Other factors to be considered. Radio-active content of rocks. Isostatic adjustment. Strength of the crust. Crustal tides. Probable condition of the earth's interior. Heterogeneous composition of crust. Suggested explanation of folding as being due to underdrag of crust by convective currents in the asthenosphere, produced by local heating and expansion, enhanced possibly by changes of crystalline form in the cooler parts.

OBITUARY.

M. René Fourtau.

By the death of M. René Fourtau, palæontological science has sustained a severe, and in some respects, irreparable loss. Born on 26th February, 1867, he was mainly educated at the College of St. Caprais, Agen. He came to Egypt in 1888, and was associated with the railway administration for some years, being for a while in control of boring operations undertaken in the Delta in connexion with bridge construction. He early became interested in the problems of Egyptian geology, and came into contact with leading palæontological authorities, such as M. de Loriol.

When the Geological Survey of Egypt was founded in 1896,

M. Fourtau at first adopted a somewhat critical attitude. As he became acquainted with those who formed its staff, he realized that they were as keenly interested in geological study as he was himself, and this led first to mutual recognition and then fuller co-operation. Acting on a suggestion made by one of the authorities at the Natural History Museum, the collection of sea-urchins in the Cairo Geological Museum was submitted to him for identification and study. The satisfactory results obtained led to his being given the rearrangement of the fossil collections at the Museum, and finally to his appointment as Palæontologist to the Geological Survey of Egypt. Here he proved a most helpful colleague, examining the rich collections which the Petroleum Research parties sent in from the field, and promptly sending them the results. The catalogues of the Invertebrates in the Cairo Geological Museum, published during this period, and illustrated by the well-known artist, M. Gauthier, of Sens, remain a permanent monument to his industry and scientific acumen.

In 1916 he entered the field of vertebrate palæontology under interesting circumstances.

The Denbighshire Yeomanry were camped at Moghara, 80 miles south-west of Alexandria, a locality already well known to geologists as an important source of Miocene fossil vertebrates. It was not long before the officers and men discovered these relics of the past, and were greatly puzzled at their presence in so arid a waste. A large crocodile skull was sent to the Cairo Geological Museum, and as a result the writer went to Moghara and explained the nature of the occurrence to the troops. It was also arranged with Col. Lloyd, the officer commanding, for the collections to be housed at the Geological Museum pending decisions as to their final destination, and M. Fourtau was deputed both to secure their safe transport, and make further examinations of the exposures. It was also decided that he should issue a description of the collections while they were still assembled at one spot, the result being the interesting memoir (*Contribution à l'Étude des Vertébrés Miocènes de l'Égypte*, Cairo, 1918), of which advance copies were issued during the war.

Fourtau also carried out several other important fossil collecting expeditions as part of his duties, these including visits to the Wadi Natrun and a closer examination of the region of North Sinai, made notable by M. Barthoux' discovery of Jurassic strata.

Special leave had been granted him to enable him to study the palæontological results, in Europe, Professors de Stifani and Stefanini placing working rooms at his disposal for this purpose in the Istituto Superiore di Geologia of Florence. He had scarcely commenced his work there before he fell ill, his death occurring on 2nd November, 1920.

Fourtau was gifted with a remarkable memory, and great powers of work. His enthusiasm brought him in close touch with a number of earnest workers in his own branch of science. He has left behind him two memoirs dealing with the North Sinai sea-urchins, which it

is hoped to publish, as also an account of the geology of the neighbourhood of Cairo and other papers.

W. F. HUME.

Frederick T. Maidwell, F.G.S.

BORN 26TH MARCH, 1872.

DIED 1ST MAY, 1921.

WE regret to announce the death of Mr. Frederick T. Maidwell, F.G.S., which took place suddenly on 1st May, at Runcorn, in his fiftieth year. He was born in 1872 at Gunnerside, in Swaledale, and a few months after his birth his parents removed to Coventry, where his father held the position of head master of St. Mark's New School until his death in 1882. The following years were full of difficulty and struggle, but after a short time spent in teaching at his father's old school, and later at the Bablake Secondary School, Coventry, he became interested in handicraft subjects, and qualified as an instructor. He held positions at Wolverhampton and Dudley, and finally in 1908 removed to Runcorn on accepting an appointment under the Education Authority there, which he retained until his death. He rendered useful service to the town in many ways, serving on the Free Library Committee, and also taking a very active interest in the local volunteer movement during the period of the war. Geology claimed a great portion of his leisure, and while in the Midlands he was an ardent member of the Warwickshire Naturalists' and Archæologists' Field Club, and several of his early papers are printed in its proceedings. He was indefatigable in observing and recording particulars of sections, old and new, in the Liverpool district, and published several papers in the Proceedings of the Liverpool Geological Society, of which he was a valued member, most of them relating to the Triassic strata of Cheshire. He also devoted some time to the study of the fossil footprints of the Trias, the results of which he recorded in two of his most important communications, in which he gave very careful descriptions of a number of Rhynchosauroid types, including webbed forms. His death removes an earnest, patient, and painstaking worker, greatly esteemed by all who knew him. He leaves a widow and three children.

T. A. J.

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- TEALL (J. J. HARRIS), M.A., F.G.S. *British Petrography: with special reference to the Igneous Rocks.* With 47 plates. Royal Svo. Cloth. £3 3s. net.
- VAN DEN BROECK (E.), MARTEL (E. A.), AND RAHIR (EDM.). *Les Cavernes et les Rivières souterraines de la Belgique.* Bruxelles, 1910. 2 vols. Svo. With 26 plates and text illustrations. Boards. £1 10s.

JUST PUBLISHED.

Catalogue of the Fossil Bryozoa (Polyzoa) in the Department of Geology, British Museum (Natural History). *The Cretaceous Bryozoa* (Polyzoa). Volume III. The Cribrimorphs, Part I, by W. D. LANG, Sc.D. pp. 269, 8 plates, and 115 text-figures. With general index, index to systematic names of Polyzoa and explanation of Plates. 8vo. Cloth. £1 10s.

The Jurassic Bryozoa, by J. W. GREGORY, D.Sc. pp. [viii] 239, 22 woodcuts, and 11 plates. 8vo. Cloth. 1896. 10s.

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The
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Monthly Journal of Geology.

WITH WHICH IS INCORPORATED

THE GEOLOGIST

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AUGUST, 1921.

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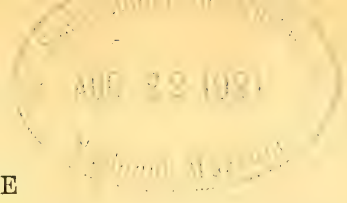
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THE GEOLOGICAL MAGAZINE

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No. VIII.—AUGUST, 1921.

EDITORIAL NOTES.

THE appearance of a new part (No. 20) of *Geological Literature added to the Geological Society's Library* in 1913 will be welcomed by all who are actively engaged in geological work. In the interests of research it is to be hoped that the issue of the records for 1914 and subsequent years will not be long delayed, as this publication is of the greatest possible value, in fact one might almost say indispensable to all who desire to keep up with the current developments of their particular branch of the subject. Our thanks are due to the anonymous compiler of this part; only those who have had experience in bibliographical work can form any idea of the amount of time and trouble which its preparation must have involved.

* * * * *

DURING the year 1921-22 Geophysical Discussions of the Royal Astronomical Society will take place on the first Friday in November, December, February, March, and May. In each case the meeting will begin at 5 p.m., and tea will be provided at 4.30. On 4th November Col. H. G. Lyons will open a discussion on the Eötvös Gravity Balance. On 2nd December Dr. Harold Jeffreys will open a discussion on the Cooling of the Earth and its Geological Effects. Fuller particulars of the meetings will appear in *Nature*, or can be obtained on application to the Assistant Secretary, Royal Astronomical Society, Burlington House, London, W.1. All members of the Geological Society are invited.

* * * * *

IN comparison with the amount of attention bestowed on the nomenclature of the igneous rocks, that of the sediments has been comparatively neglected. All field-workers in stratigraphical geology must have been often conscious of a want of precision in the terms at their disposal for the description of the rock-types encountered in the course of their work. This applies perhaps with the greatest force to the arenaceous types of sediment. The special point that we have in mind is the want of a satisfactory field-term to describe the very hard fine-grained rocks that are so abundant for example in the Silurian system in most parts of this country. These are generally called *grits*, but this is a misapplication of the

word. The essential feature of a true grit is that it should be gritty, that is, breaking and weathering with a rough uneven surface, which these rocks do not. A true grit, such as the Millstone Grit, is of very irregular grain, and usually more or less porous, whereas the Silurian rocks here referred to are of very fine texture, even-grained, and very closely and tightly cemented. The name sandstone is hardly applicable, since to most people it connotes the idea of a somewhat soft and crumbly rock. The old term greywacke is better, but unfortunately it is not English. What is wanted is a good Anglo-Saxon word, not already used in some other quite different sense, and if possible self-explanatory. During the present field-season we commend this problem to our readers, and shall be glad to receive any communications on the subject that may suggest themselves. There are other problems of a similar nature; for example, What is a quartzite? Is a marl necessarily calcareous? And so on. Many more will no doubt occur to our readers. However, let the discussion, if any, be confined to one at a time.

* * * * *

It is quite obvious that in geological research work two sets of names are required. One, of a rough and ready character, for use in the field; the other, for detailed petrographical descriptions in the laboratory. Among the igneous rocks we have excellent examples of the first class in the good old names felsite and greenstone. It is true that felsite is a barbarous word, but it is consecrated by usage, while greenstone is eminently descriptive, and both are well adapted for field notes. Later on, the rock can be examined and analyzed and assigned to its proper pigeon-hole in the system of petrographic nomenclature specially fancied by the writer. Most of the common names for the sediments do fulfil the requirements of field-work, but there are not quite enough of them, so that many are used in more than one sense. Every one is acquainted with the trouble caused by endeavours to find out what is really meant by *schiste* and *Schiefer*, and the two senses of the word cleavage are a perpetual stumbling-block to beginners. We are far from wishing to increase the number of technical words or of words used with technical meanings in addition to their ordinary significance, but it is evident that a few more are really needed.

ORIGINAL ARTICLES.

The Jurassic and Lower Cretaceous Rocks of Northern Sinai.¹

By W. F. HUME, D.Sc., F.R.S.E., A.R.S.M., R. FOURTAU,
F. W. MOON, B.E., F.G.S., and H. SADEK, B.Sc.

FOR many years this portion of Egypt had remained a blank so far as its geological structure was concerned, and when the geological map of Egypt was issued by the Survey Department in 1910 this extensive area was deliberately left uncoloured. Efforts were made by the writer² to interest the various parties which were mapping the topography of this region, but the fossils submitted by them only indicated the presence of beds of Upper Cretaceous age, including a facies identical with that developed in the Abu Roash hills near Cairo.

New and unexpected light was thrown on this problem when M. J. Barthoux commenced a geological map of the Isthmus of Suez on behalf of the Suez Canal Company. He was deeply impressed day by day with a sight of the unknown hills lying behind the sand-dune belt to the east, and finally resolved to cross the waste and solve the mystery of their structure. His energy and resource (shown later during the war by his escape from Germany after being captured near Soissons) were rewarded with success, for in the collections which he brought to the Cairo Geological Museum for study, M. Fourtau recognized species of sea-urchins of definitely Lower Cretaceous age. This indicated that the locality visited was of exceptional interest, and finally led to the discovery of the now famous Jurassic strata of Gebel Maghara. The species thus identified were *Pseudodiadema libanoticum* de Loriol, *Holectypus macropygus* var. *neocomiensis* Gras, and *Pliotoxaster Collegnoi*, race *orientalis*, Fourtau (R. Fourtau, "Echinides Aptiens d'Égypte et de Syrie," *Bull. de l'Inst. Egypt.* 1913, pp. 43-58). At an early stage in the further examination of this area, M. Barthoux kindly invited the writer to accompany him, but as this was impossible owing to other duties demanding attention, it was arranged for M. Fourtau to join him. This has led to a very careful palæontological and stratigraphical study of the area by M. Fourtau, the results of which will appear in due course.³ M. Douvillé was associated with M. Barthoux in the earliest publications on this subject, one of the first notes being that on "Le Jurassique dans le désert à l'est de l'isthme de Suez",

¹ Published by permission of the Surveyor-General, Egyptian Government.

² This note has been written by Dr. W. F. Hume (hence termed the writer), but the facts on which it is based largely depend upon the work of those who are associated in the title as co-authors.

³ Owing to the death of M. Fourtau since these words were written, it is uncertain how far this can be fulfilled, but every effort will be made to publish the work in so far as it was completed by this indefatigable and enthusiastic student, whose early loss to science we lament.

by J. M. Barthoux et M. Douvillé (*Comptes Rendus Ac. Sciences*, t. 157, p. 265, 28th July, 1913).

In this paper it was pointed out that no Jurassic formations were previously known in the south-eastern portion of the Mediterranean basin between Tunis and North Palestine, and that in Sinai itself they are only found in the most northern of the hill ranges, of which Gtera (Gedeira), Hameir (Hamaiyir), and Maghara are the principal component hills. Here, however, there is a notable development,

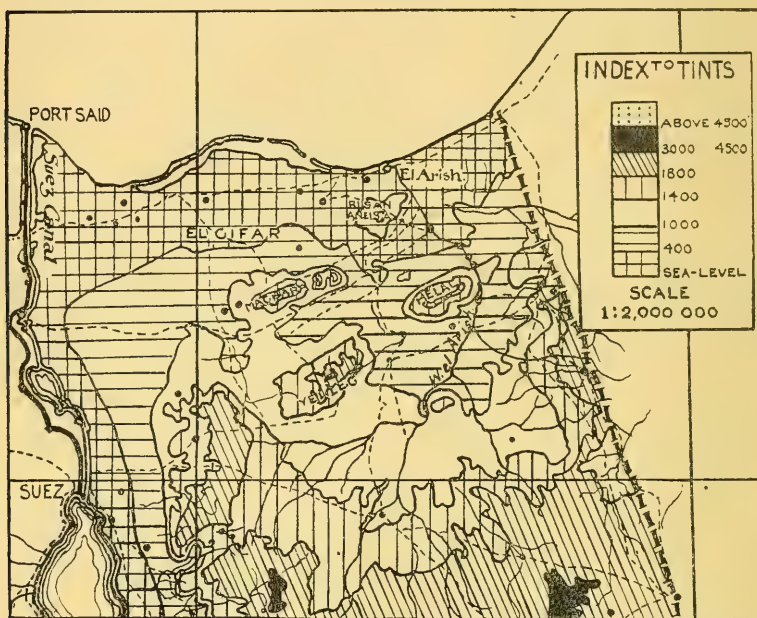


FIG. 1.—Orographic map of Northern Sinai.

the lowest strata being characteristic (a) "Nubian Sandstone", with vegetable remains. They are highly inclined, and their base is not seen. These are followed by (b) an alternation of grits and marls having an estimated thickness of 80 metres, overlain by greyish limestones (about 25 metres thick), with *Terebratula fimbria*, *Rhynchonella Edwardsi*, and corals of the genera *Thamnastrea* and *Montlivaultia*. These are the first beds of the Bajocian (Inferior Oolite), which are succeeded by limestones becoming yellowish and alternating with marls, their dip diminishing little by little. The fossils are well preserved, but often broken, especially the ammonites, which are somewhat rare, and represented by simple fragments. These beds are grouped by the authors under three divisions, (c) those of Bajocian age, with *Cœloceras Humphriesi*, *Terebratula Phillipsi*, *T. perovalis*, etc. (d) Bathonian (Great Oolite) with *Æcotraustes subfuscus*, *Pholadomya* cf. *Aubryi*, *Eudesia cardium*,

etc. (e) Callovian, with *Reineckia anceps*, *Stepheoceras* sp., *Phylloceras* sp., *Modiola solenoides*, *Gervillia aviculoides*, and very abundant *Rhynchonella Orbigny*.

Beds of lithographic limestone (f) form a horizon easy of recognition, and are best developed in Gebel Hamaiyir. They have furnished some sections of *Belemnites* and a cast of *Quenstedticeras*. At the same level have been found a fragment of *Pachyceras*, large *Terebratulæ*, related to *T. Lamberti* and *T. suprajurensis*, as also *Zeilleria Parandieri*. These beds were regarded as representing the Upper Callovian and Oxfordian, perhaps even the Upper Jurassic. (g) This latter horizon seemed to be indicated by a fragment of a *Lytoceras*, having the characters of *L. Liebigi* var. *strambergensis*.

The Jurassic strata are thus developed on a large scale in this portion of Egypt, as are also the Lower Cretaceous beds, which overlie them in great thickness.

(h) The Lower Cretaceous strata were noted as represented by limestone containing grains of quartz or small ferruginous oolites. These were stated to have yielded *Knemiceras syriacum*, *Protocardia hillana*, *Eoradiolites Rousseli*, *Neithea quinquecostata*; a lower stratum seemed particularly rich in species of large Trigonias, *Tr.* like *crenulata* and *Tr.* like *sinuata*. These beds were regarded as the extension of the well-known Lower Cretaceous formations of the Lebanon, where they represent the "Vraconnian". Like the Jurassic, these had never yet been recorded, either in South Palestine or in Egypt. It is of interest to note, however, that M. C. Barthoux has also noted the *Knemiceras* beds at the foot of Gebel Shabrawet, one of the hills near Faied Station (Ismailia-Suez line) to the west of the Suez Canal.

(i) The highest beds of the series studied are yellowish, very fossiliferous limestones of typically Cenomanian age, with such characteristic fossils as *Neolobites Vibrayei*, *Exogyra flabellata*, and *Orbitolina concava*, race *minor*.

The larger work, "Les Terrains Secondaires dans le Massif du Moghara à l'est de l'isthme de Suez d'après les explorations de M. Couyat-Barthoux et M. H. Douvillé," deals with the palæontology of the area in greater detail, full descriptions being given of the principal *Cephalopoda*, *Gasteropoda*, *Lamellibranchiata*, *Brachiopoda*, and *Foraminifera* in the various formations.

The results differ in no important respect from those recorded in the first paper; the *Knemiceras* is, however, *K. Uhligi* Choffat, and not the closely related *K. syriacum*.

The war brought further study of North Sinai to a conclusion for some years, and only in the season of 1918-19 did M. Fourtau (acting in his capacity of palæontologist to the Geological Survey of Egypt) commence a detailed examination of this portion of Northern Sinai, extending his researches eastward to embrace the massif of Gebel Helal in 1919-20. In the latter period Messrs. Moon and Sadek examined an area of some 8,000 square kilometres in North-

Western Sinai in connexion with the petroleum research programme of the Egyptian Government, the object being to obtain the fullest details possible as regards the stratigraphy and structure of the region, with the question of the indications of petroleum in the forefront of the research. The writer had hoped to have personally examined some interesting portions of this area, but other field duties intervened. Nevertheless, he was enabled during the early days of May, 1920, to visit that portion of the region in which these newly discovered formations are best developed. M. Fourtau kindly prepared a programme which would enable the writer, with Messrs. Moon and Sadek, to obtain a broad view of the northern series of ridges (Gebels Risan El Aneiza, Mistan, Lagama, the main Maghara range), the party crossing Sinai from El Arish to Ismailia.

The characters of the Risan El Aneiza massif were practically unknown, and the party subdivided itself during the course of the examination. On reuniting in the evening it was found that interesting results had been obtained. Fourtau, following the southern boundary of the hills, had found Jurassic strata in Ras Jehan, while Sadek discovered beds of the same age in the centre of the range, forming part of a faulted-in region to the east of Ras El Ahmar. The writer was accompanied by Sheikh Shehata (brother of the head sheikh of the Terrabin), who, under M. Fourtau's influence, had become a keen and discriminating collector. While examining the Ras Ahmar ridge, the Sheikh was observed busily at work, just below the summit, and, on joining him, the writer had the satisfaction of meeting old Lower Greensand friends from the Isle of Wight, such as *Terebratula sella* and a typical species of *Gervillia*. Later in the day a ridge was visited which yielded a typical Aptian fauna, the research closing with the discovering of Albian (Gault), crowned by the Cenomanian known to be present here at the western end from Barthoux's researches. Thus it may now be stated that the Jurassic and Lower Cretaceous rocks are typically represented in this north-eastern extension of the Maghara fold.

The party subsequently studied the typical exposures of Jurassic and Lower Cretaceous age in the Mistan, Um Mafruth, Lagama, and Maghara hills, type examples of the whole series being examined in turn. Thus were seen the Ammonite beds of the Bajocian series bordering the east side of the Wadi Maghara, the *Bothryopneustes* beds, and those rich in *Rhynchonella Orbigny* of the Callovian, the *Collyrites bicordata* bed of the Oxfordian and the representative of the Coral Rag. The Lower Cretaceous beds were most strikingly displayed in the neighbourhood of Bir Lagama, and from thence the succession traced over the pass of Aseifer into the valley to the north of Gebel Mandur. Species of *Puzosia* seemed the commonest cephalopoda at the base of the series, accompanied by numerous species of *Trigonia* (*T. Picteti* Coq. *T. pseudo-crenulata* Nötling). M. Douvillé considers that certain of the limestones with fine ferruginous oolites from Bir Lagama have furnished a certain number

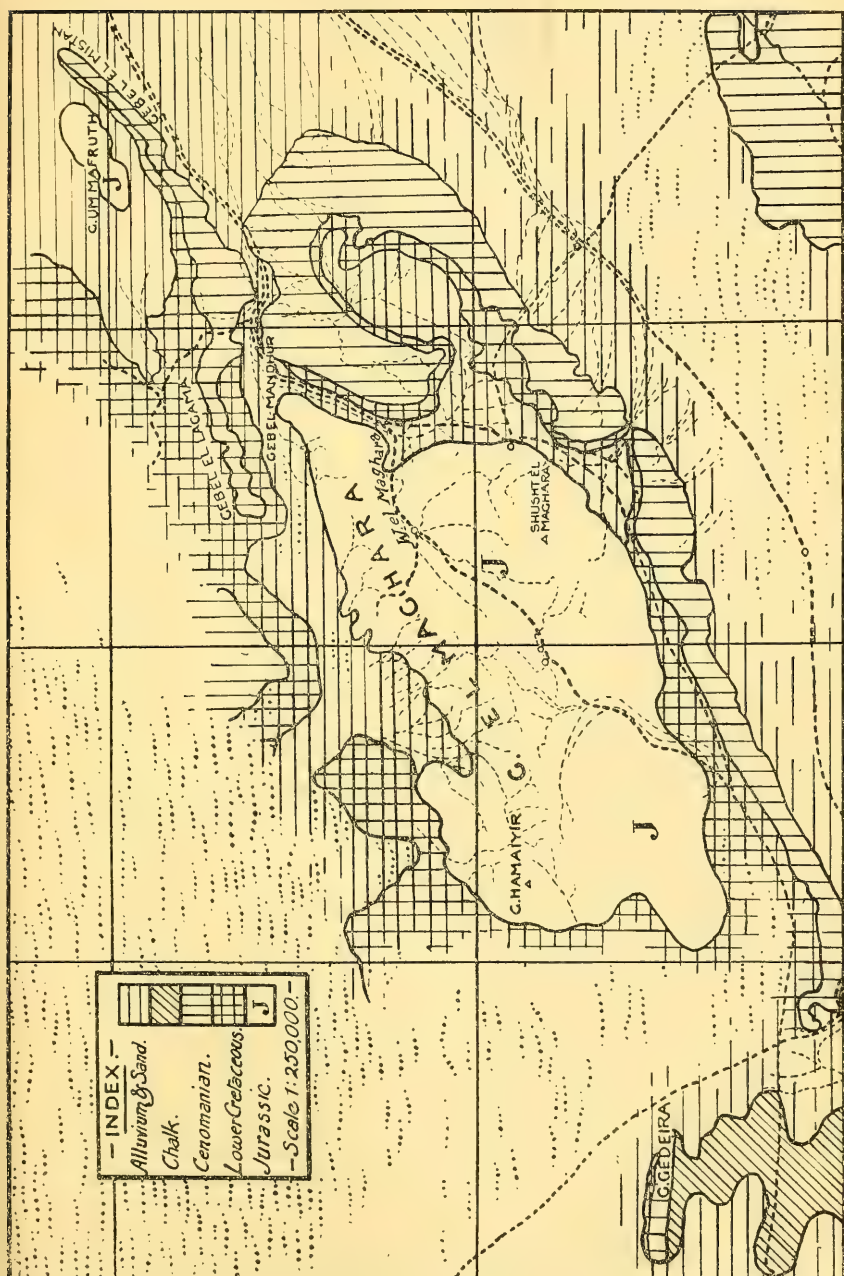


Fig. 2.—Geological map of the Maghara range and neighbourhood.

of cephalopods which are definitely of Barremian age (equivalent roughly to the Atherfield clay of the Lower Greensand in England and higher than the Neocomian). These include species of *Lytoceras*, *Costidiscus*, *Phylloceras*, *Desmoceras*, and *Crioceras*. The beds with which the writer became acquainted are, however, frankly Aptian (Lower Greensand), and as stated above contain species of *Puzosia* (*P. Matheroni* d'Orb, *P. Angladei*, Sayn), and of *Douvilleiceras* (*D. Meyendorffi* [Sinzow]). *Nautilus Lallieri* d'Orb. is also abundant.

A familiar British fossil found in these beds is *Terebratula sella* Sowerby.

As we mounted the pass, the series was followed in ascending succession by beds with an abundant *Echinoconus* and large Gasteropoda. A layer containing small ferruginous ammonites also attracted our attention. At a point where the pass steepens, and the path takes a sharp turn, are strata very rich in a beautiful variety of simple coral, *Trochocyathus* sp., etc. These beds M. Fourtau regards as typically Albian (Gault). At the summit of the pass are beds crowded with a foraminifer, *Orbitolina* cf. *concava* Lam. Finally, in the descent, the typical *Exogyra flabellata* was met with, indicating the presence of the Cenomanian formation already so familiar in other portions of Egypt and the Sinaitic peninsula.

M. Fourtau had kindly prepared the following notes for inclusion, these giving further details as to the character of the Jurassic strata in the Maghara area.

"The Lower and Middle Jurassic are very well represented at Maghara, but in consequence of the sedimentation having been continuous and there being both recurrence of faunas and of facies, it is difficult to determine the precise limits of the different horizons, Bajocian, Bathonian, Callovian, and Oxfordian.

"The Bajocian is poor in fossils, and its lower boundary with the grits difficult to define, so that one may regard the basal grits of the central dome of Maghara as possibly Liassic, though they might equally represent the earliest strata of the Inferior Oolite. The limestones are in general grey or blackish, and some of the beds are highly oolitic. The sea-urchin fauna is poor but characteristic. *Stomechinus bigranularis* Link, *Pygaster* cf. *semisulcatus* Ag., *Rhabdocidaris coploides* Ag. and at the top, *Holcotypus depressus* Leske. The Brachiopods are represented by special forms of *Terebratula*, the *Parathyris* of Douvillé with *Zeilleria subbucculenta* Chapuis and Devalque. The Cephalopods are especially species of *Cœloceras*. As regards the Lamellibranchs, these are mostly rare, with the exception of a *Nucula* related to *N. tenuistriata* Sow.

"M. Douvillé places an Ammonite horizon in the Bajocian, following Barthoux in calling this the yellow limestones. These beds appear to us to have their place better at the base of the Bathonian, as they contain certain fossils more or less characteristic of that formation, such as *Eudesia cardium* Link, *Terebratula quillyensis* Bayle, and *Rhynchonella Orbignyi* Oppel. It is to be

observed that Douvillé (1918, page 34) noted that in this bed, which still contained Bajocian species, were already a number of species of Bathonian age.

"The Cephalopods are well preserved in these beds, the following being the most commonly represented: *Cœloceras Humphriesi* Sow., *Phylloceras disputabile* Zittel, and *Ph. mediterraneum* Neumayr, and the new types *Ermoceras mogharensis* H. Douv. and *Thamboceras mirum* H. Douvillé. Above these strata follow limestones with *Terebratula quillyensis* and *Ostrea (Liogryphæa) costellata* d'Orb., then a succession of beds of grits and limestones, with *Rhynchonella Orbigny*, *R. concinna* Sow., *R. obsoleta* Sow., and *Ostrea (Arctostrea) avita* Douvillé. The Bathonian must be considered as having preceded the oscillations of the grits. The echinid fauna is somewhat poor in known forms, except for the spines of *Plagiocidaris bathonica* Cotteau and *P. meandrina* Ag. The Mollusca have been described by Douvillé, it is to be noted that some of these reappear in the Callovian and even in the Oxfordian. The Callovian (if its base be placed at the level of the limestone with flint nodules above the last band of grit) is well represented by oolite and ferruginous limestones characterized by an abundance of small Atelostomatous sea-urchins of small size, closely related to *Pygurus*, but having their periproct in a marginal or supramarginal fossette, which brings them closer to the Cretaceous *Bothriopygus*, and which places them in the new genus *Bothryopneustes* R. Fourtau. Above follows a great thickness of blue-green marls broken by a band containing *Eudesia cardium* and *Pygurus* sp. nov.

"The limit between the Oxfordian and the Callovian is very difficult to determine, but certain beds are indisputably Oxfordian. One of these contains *Terebratula Lamberti* Douv., *Myoconcha Rathieri* d'Orb., *Ostrea (Arctostrea) amor* d'Orb., *Perisphinctes varicostatus* Buckland, *Aspidoceras Babeau* d'Orb., *Ctenostreon proboscideum* Phillips, *Pecten fibrosus*, Phill., and *Rhabdocidaris capremontana* Desor; while above are limestones with *Collyrites bicordata* Desmoulins.

"Above these limestones commences what we regard as the Upper Jurassic, which is here represented by a stage including both Coral Rag and Kimmeridge Clay, a stage established in Portugal by Choffat, the Lusitanian. It commences with a thick mass of dolomitic limestones containing *Diplocidaris gigantea* Ag. and *Gymnocidaris (Hemicidaris) Agassizi* Roemer, fossils distinctly characteristic. The upper part corresponds to the "Glandarienkalk" of Syria, with *Plegiocidaris Choffati* de Loriol, *Pseudocidaris lusitanica* de Lor., and numerous crinoid stems belonging mainly to the genus *Millericrinus*. An interesting facies is presented by a dolomitic white limestone with mollusca changed to calcite, of which fine samples have been collected. The Portlandian and Tithonian are not represented."

The result of the operations of the Geological Survey and

Petroleum Research has thus been in the first place to re-study the great north-east-south-west fold of Maghara, etc., in which the Jurassic and Lower Cretaceous strata are best developed, and to prove the extension of these strata to the eastward in the Risan el Aneiza hills. Further, it has enabled the writers to become personally acquainted with the trend of the researches already undertaken, enabling them to attack the problems awaiting solution with enhanced knowledge.

There remains, however, a main question which will have occurred to most geologists and demands an answer. Why are these formations so strongly developed in the Maghara fold, yet so strikingly absent further south where Cenomanian strata of the most typical kind overlie a great thickness of Nubian Sandstone,¹ in which no trace of fossiliferous formations are to be met with?

We believe the answer to be that we are dealing with the phenomenon of *lateral variation* on the large scale. To the south of this region lay a great granitic-metamorphic continent. As its borders were approached, the strata became more and more sandy, further away from it marine formations were developed at an earlier age than further to the south. The theme dealt with by the writer in his paper on the "Secular Oscillations", read before the Geological Society, has expanded (W. F. Hume, "Secular Oscillation in Egypt during the Cretaceous and Eocene periods," *Q.J.G.S.*, vol. lxvii, 1911, pp. 118-48). We can no longer speak of the "Nubian Sandstone" as of Cretaceous age; it is a lithological condition which, beginning in late Carboniferous times both in Sinai and Eastern Egypt, was developed in Northern Sinai during the Trias and Lias, and also alternating with the fossiliferous Jurassic strata, as may be well seen in ascending the main Maghara crest. If these beds of known date were not present, it would be impossible to distinguish the sandstones from those regarded as of typically "Nubian Sandstone" character elsewhere.

The writer did not himself note so marked an alteration in the Lower Cretaceous formations. For Egypt itself he has already directed attention in the above paper to the breaking up of the Upper Cretaceous series by "Nubian" Sandstones, these lying very markedly between strata of Cenomanian and Turonian age; whereas south of that latitude both the fossiliferous Cenomanian and Turonian strata are represented by sandstone alone. We therefore scarcely expect, in pursuing the research further, to find fossiliferous Jurassic and Lower Cretaceous strata south of the fold in which they are at present known, but rather that elsewhere they will be "Nubian Sandstone". Much light has been thrown by Messrs. Moon and Sadek's work on the *structure* of the north-western portion of North Sinai, which embraces this area. M. Barthoux had already noted that the area was folded, constituting a series of

¹ See Ball on the "Geography and Geology of West Central Sinai", reviewed in *GEOL. MAG.*, 1917, p. 80.

anticlines in which further to the south Cretaceous beds formed the crest, while the synclines were occupied by Eocene strata. These folds trended from north-east to south-west. It is now shown that these folds are markedly asymmetrical with their steep sides generally directed south-eastwards. The result is that the strata are not only thrown into regular anticlines, but dome structures are numerous. Naturally there is also much faulting, but not sufficient to obscure the fundamental folding. Perhaps the most striking feature is the existence of a remarkable narrow "steep zone", an extremely narrow fold which traverses the Maghara range, and has been traced over many kilometres. This will be described in detail by the writer's colleagues in the work now being prepared by them.

Finally, an indication may be given of the general theoretical conceptions which have appeared to arise from the most recent studies. The first is the conclusion that the folding which closed the Eocene period was north-eastward-south-westward in Sinai, changing to an east-west trend in Egypt itself, and perhaps again resuming the north-eastward direction in the Libyan Desert, for example, in Baharia Oasis. By this folding the deeper-seated granitic core was brought either near or to the surface, and may subsequently have acted as a buffer against which the already slightly folded sedimentary strata were further buckled into asymmetric folds under pressures continuing to act from the north-west.

It is noticeable that these pre-Miocene strata both in Sinai and Egypt show no trace of being affected by the series of movements which produced the "rift" effects. In the latter the north-westward trend of the strata is broadly developed between the greater fault lines (presumed to be continuous) which border the depression of which the Gulf of Suez occupies the centre. These faults have been proved with certainty at the base of the Red Sea Hills northward of lat. 26° N., and also at the feet of Gebel Ataka, near Suez, and Geneife, but a great deal of detailed work is still required before the continuous nature of the major fault can be established for the Egyptian side of the larger Gulf of Suez depression. On the Sinaitic side the major fault has been traced in much detail by Barron, Ball, Barthoux, and Moon and Sadek. It is hoped later to discuss the facts collected in relation to "Rift" theories.¹

On *Ammonites* from Spitsbergen.

By L. F. SPATH, D.Sc., F.G.S.

(Concluded from p. 305.)

There appears to be a good deal of variation in the Lower Triassic succession of the different parts of Spitsbergen, even between Ice Fjord and Bell Sound, at which latter *Gyronites nathorsti* J. Böhm

¹ This has taken place since this paper was handed in for publication, the writer opening a discussion on the subject at the Geological Society meeting of 8th June, 1921.

occurs in soft shales. The grey sandstones with a Lamellibranch fauna of Werfenian age from Axel Island,¹ again, represent quite a different facies.

The difficulties encountered in studying the Lower Triassic forms, and due, chiefly, to the conflicting evidence of the various matrixes, and to the fact that some of the best-preserved examples were found loose, are met with again in dealing with the Middle Triassic specimens.

Monophyllites sp. cf. *sphærophyllus*, Hauer sp.,

Ptychites cf. *trochlaformis*, Lindström sp.,

Ptychites ? sp. cf. *tibetanus*, Mojsisovics,

? *Gymnotoceras* cf. *laqueatus*, Lindström sp.

are referable to the Middle Trias (Anisian), though they are only preserved as impressions in a black shale that apparently corresponds with the "Thin Paper Shales" (D₃) of Professor Gregory's section I. This shale is full of comminuted fragments of shells, and quite distinct from any other matrix, and it may be added that the two vertebral centra of *Aphaneramma rostrata* figured by Dr. A. Smith-Woodward have this matrix, whereas the skull is preserved in a hard nodular limestone reminiscent of the *Posidonomya* shales.²

Stolley³ recorded a *Monophyllites* from the *Daonella* beds, and considered these to be of Ladinian age, and the equivalent of the Wengen beds. He found *Nathorstites*, which characterizes Upper Triassic beds on Bear Island and in British Columbia, only a little higher, and thus would draw the boundary-line between the Middle and Upper Trias just above the *Daonella* beds. The large specimen of *Monophyllites*, mentioned above, resembles *M. sphærophyllus* Hauer sp., but not *M. wengensis* Klipstein sp., and its association with *Ptychites* and *Gymnotoceras* suggests an Anisian age.⁴

The specimen of *Gymnotoceras*, unfortunately, does not show the inner whorls,⁵ and has a different matrix from all the other examples of *Gymnotoceras* in the collection. These occur with *Lingula lindströmi* J. Böhm,⁶ and the other Ammonites given in the list

¹ Wittenburg, "Üb. Werfen. Sch. v. Spitzbergen": *Bull. Acad. Imp. Sci. St. Pétersb.*, ser. VI, 1912, pp. 947-8.

² These specimens are from Sticky Keep, whereas the first three in the above list are from "Bluff, above entrance to Flower Valley, over nodule bed", (Escarpment Shales of Professor Gregory's Section II). The last (*Gymnotoceras*), which has a more slaty (worn) aspect, is from "Sassen-Bay".

³ "Z. Kenntn. d. Arkt. Trias.": *N. Jb. f. Min.*, etc., vol. i, 1911, p. 117.

⁴ Among 3,500 Bosnian Ammonites from the "*trinodosus*-zone", recently named by the writer, the genera *Ptychites* and *Monophyllites* were represented by 640 and 314 specimens respectively, and, besides Arcestds, the dominant element of the fauna.

⁵ There is a certain resemblance in ornament to *Protrachyceras sverdrupi* Kittl ("Die Trias-Fossil. v. Heureka Sund": Report 2nd Norw. Arct. Exped. in the *Fram*, 1898-1902, No. 7, 1907, p. 39, pl. iii, fig. 9) also associated with a *Daonella* very similar to the Spitsbergen form.

⁶ This author (loc. cit., p. 13) has a black, fine-grained limestone with this *Lingula* above the Lower Trias, and since the *Lingula* also occurs in slabs with *Daonella* he considers it of Ladinian (Middle Triassic) age. The form here

below, in a limestone which is very compact and black when fresh, but brownish, softer, and more flaggy when weathered, and which may correspond with the black, fine-grained limestone referred to by J. Böhm. The forms of these black limestones and calcareous flags (as distinguished from the above shales) are :—

- Gymnotoceras laqueatum* (Lindström), common.
 „ *falcatum* (Mojsisovics).
 „ *geminatum* (Mojsisovics), common.
Danubites ? sp.
Tropigastrites ? cf. *polygyratus* Smith.
Monophyllites cf. *spetsbergensis* (Öberg).¹

The evidence, however, is by no means satisfactory ; for very similar black limestones, weathering to various lighter colours, occur in nodules in the Lower Trias, and it should be mentioned that *Gymnotoceras falcatum* is labelled [by error ?] “ Nodule-bed, Trident”, and one specimen of *G. cf. laqueatum* comes from “ E basement bed of Trident”. The latter has the matrix of some thirty specimens of *G. geminatum* (Mojsisovics), comparable with the two crushed specimens figured by Mojsisovics² from the black calcareous shales of the Hyperite Hat. It agrees with the “ Calcareous Flags above nodules”, referred to above, characterized by a *Pseudomonotis*, but it may only represent a more weathered condition of the black crystalline limestone that contained *Lingula*, *Monophyllites*, and [doubtfully] *Gymnotoceras falcatum*. On the other hand, a similar *Pseudomonotis* occurs in the *Ptychites*-beds.³

Two quite indeterminable impressions of Ammonites are labelled “ Phosphate Series, near Botanists’ Camp, de Geer Valley Delta, Sassen Bay”, and probably came from one of the Oozy Mound Beds (E) of Professor Gregory’s section I. Phosphatic shales are mentioned by Nathorst,⁴ as occurring both in the Lower and, more frequently, in the Middle Trias (*Daonella* shales), but the more involute impression (unfortunately crushed quite flat) may even be a *Nathorstites*, and thus indicate a Carnian horizon.

The only fragment of an Ammonite, actually associated in the same slab with *Daonella*, unfortunately is indeterminable. On the

referred to *L. lindströmi*, like *Gymnotoceras falcatum* and *Monophyllites* cf. *spetsbergensis*, are preserved in a black limestone that is characterized by the brownish calcite, replacing the shells ; but *Arctoceras* may be similarly preserved.

¹ This small form is characterized by three saddles, like Himalayan species of the group of *M. suessi*, figured by Diener (1895, pl. xxxi), but in shape more like *M. nara* Diener or *M. spetsbergensis* (Öberg).

² Loc. cit., 1886, p. 49, pl. ix, figs. 13, 14 only. Many examples of this form from “ West of Fortress”, near Cape Staratshin, and from Trias Point, North Side of Van Keulen’s Bay, Bell Sound, are in Mr. Reynolds’s Collection.

³ After seeing Professor Gregory’s section I, the writer would put this *Gymnotoceras* fauna into D₁ (“ Earthy Limestone”).

⁴ “ Beitr. z. Geol. d. Bären- Insel, Spitzb. und d. Kön. Karl Landes” : *Bull. Geol. Inst. Univ. Upsala*, vol. x, 1910–11, Nos. 19 and 20, p. 352.

TABLE OF TRIASSIC SUCCESSION.

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E₃: *Atracites* sp.
E₂: *Daonella* (*Monoph.* cf.
wengensis, *Ptychites*).
E₁: ?

other hand, Mr. Reynolds's Collection includes, besides *Monophyllites* cf. *wengensis* (which seems to confirm Stolley's evidence, referred to above), the following forms from the *Daonella* beds:—

Ptychites lundgreni, Mojsisovics.

„ sp. ind. (Mojs., p. 92, pl. xiii, fig. 2).

„ *concentricus*, Öberg sp.

? *Tropigastrites* sp.

Many of the *Ptychites* are crushed and resemble the oxycone *Nathorstites*, but the examples that have the suture-line preserved indicate the generic position of the forms.

II. JURASSIC.

The list of Jurassic Ammonites includes the following forms:—

Amæboceras cf. *nathorsti* Lundgren sp.

„ cf. *kitchini* Salfeld sp.

„ cf. *alternans* (v. Buch) auct. sp.

Pictonia ? cf. *normandiana* Tornquist

„ sp. cf. *bigoti* Tornquist (= ? *A. triplicatus* Lindström, non Sowerby, pl. iii, fig. 2 only).

„ sp. ind.

“*Perisphinctes*” (? *Pictonia*) sp. ind.¹

Rasenia cf. *uralensis* d'Orbigny sp.

„ sp. n.? cf. *trimera* (Oppel) de Loriol sp.

„ ? cf. *swindonensis* Pavlow sp.

Virgatites cf. *polygyratus* (Trautschold) Pavlow sp.

„ cf. *scythicus* Vischniakoff sp.

„ cf. *nikitini* Michalski sp.

Craspedites sp. cf. *nodiger* (Eichwald) Nikitin sp. e.p.

„ sp. nov.?

Piesetrobelus cf. *magnificus* (d'Orbigny) Pavlow.

They were collected at Cape Staratshin, Ice Fjord, and at “Fastness Camp”, east of that Cape, with the exception of one slab of black shale, full of large examples of *Amæboceras* cf. *nathorsti*,² that is labelled “Sassen Downs”. All the other specimens of this form, from Cape Staratshin, are preserved in a softer, micaceous, black shale, which also contains *A.* cf. *kitchini*³; some more evolute examples seem to be closer to the forms described as *A.*

¹ A number of specimens of comparable *Perisphinctids* and *Virgatites* from Cape Delta, Sassen Bay, are in the Reynolds Collection.

² Lundgren, “Jura und Trias Fossil, etc.”: *Bihang till K. Svenska Vet. Akad. Handl.*, vol. viii, No. 12, 1883, p. 6, pl. i, figs. 1, 2. Most of the examples, representing impressions of large individuals, appear to be coarser than Lundgren's figures, and may belong to the form recorded as *Cardioceras* n.sp. from black, carbonaceous shales of the King Charles's Isles by Pompeckj (“Marines Mesozoic. v. König-Karls-Land”: *Öfversigt af k. Vet. Ak. Förh.*, 1899, No. 5, p. 458).

³ Very close to examples in the British Museum, identified by Dr. Salfeld, from a very similar carbonaceous shale of Culgower and Cromarty, Scotland, also containing *Rasenia*.

alternans from apparently contemporaneous beds of Greenland,¹ and, on account of the single costation, also to the form referred to *Amæboceras* cf. *bauhini* (Oppel), by Ilovaïsky, from his highest bed D₄.² Lahusen³ refers to this "Schwarzer Brandschiefer" of Spitsbergen, with *A. nathorsti*,⁴ as containing *Aucella radiata* and *Aucella bronni*, but though some of the slabs of this micaceous shale with *Amæboceras* contain isolated *Aucella* of the type of *A. spitsbergensis* and *A. reticulata* Lundgren, these *Aucella* are more plentiful in other examples of this shale, not associated with Ammonites.

In the finer-grained, non-micaceous shales that Lindström⁵ and Lundgren⁶ mention as containing *A. triplicatus*⁷ and *Aucella*, shells of the latter genus also are very abundant, but the *Aucella mosquensis* probably was misquoted for a plicate variety of *A. pallasii*. This occurs together with *A. bronni* Rouiller, so that a Kimmeridgian age (zone of *Aucella bronni* of Lahusen) is most probable. Pompeckj,⁸ however, records *Perisphinctes* cf. *triplicatus* (Lindström), together with *Aulacostephanus* (and corresponding *Aucella*), thus suggesting a higher horizon in the Kimmeridgian (Hoplitenschichten of Lahusen) than is indicated by the forms of *Pictonia* which belong to the lower *alternans* beds. The Ammonite impressions in this black shale, characterized by its weathering to various colours, unfortunately are badly preserved; there is great resemblance to the forms of *Pictonia* quoted above, but also to *Perisphinctids* of the *achilles-decipiens* group. The primary ribs distinguish the forms from *Rasenia*, e.g. *R. triplicata* (Sow. in Damon),⁹ or the still higher *Virgatites*. On the other hand, one example agrees very well with *V. polygyratus* (Trautschold) in Pavlow,¹⁰ so that it appears probable that a number of horizons

¹ J. P. J. Ravn, "On Jurass. and Cret. Foss. from N.E. Greenland": *Mus. Min. Géol. Univ. Copenhagen, Comm. Paléont.*, No. 10, 1911, p. 486, pl. xxxvi, figs. 1-3.

² "L'Oxf. et le Séquan. d. Gouv. de Moscou et de Riasan": *Bull. Soc. Imp. Nat. Moscou*, n.s., vol. xvii (1903), 1904, p. 273, pl. xi, fig. 2.

³ "Üb. d. Russ. Aucellen": *Mém. Com. Géol. St. Pétersb.*, vol. viii, No. 1, 1888, p. 44.

⁴ Additional examples of *A. nathorsti* in the Reynolds Collection come from the south side of Van Keulen's Bay, Bell Sound, and from Green Harbour (south-west).

⁵ "Om Trias och Jura- Först. fr. Spetsbergen": *K. Svenska Vet.-Akad. Handl.*, vol. vi, No. 6, 1866, pp. 10, 19.

⁶ Loc. cit., 1883, p. 3.

⁷ Sowerby's *A. triplicatus* (xcii, 2) is a *Rasenia*; *A. triplex* (ccxciii, 4) and *A. trifidus* (ccxcii) are Corallian *Perisphinctids*.

⁸ In Nathorst, "Eine vorläuf. Mitt. v. Prof. J. F. Pompeckj üb. d. Altersfrage d. Juraablag. Spitzbergens": *Geol. Fören. Förh.*, vol. xxxii, Heft 6, Nov. 1910, p. 1503 (table).

⁹ *Supplement to the Geology of Weymouth, etc.*, new ed., 1888, pl. xiii, fig. 3.

¹⁰ *Études, etc.*, i, 1889, p. 60, pl. iii, fig. 3a only. Trautschold's original (*A. polygyratus* Rein., "Z. Fauna d. Russ. Jura": Moskau, 1866, p. 19, pl. iiii, fig. 4) is quite different.

of the Kimmeridgian and Portlandian may be represented, and that the so-called *A. triplicatus* includes a variety of forms.

The specimen referred to *Virgatites* cf. *scythicus*, Vischniakoff sp.,¹ is very close to, but more evolute than, Michalski's figure 2² of that species, and has the same fine, dichotomous costation. It is preserved in a slightly different shale, without *Aucella*, that resembles the matrix both of *Rasenia* and of that of the gigantic *Virgatites* cf. *nikitini*, which latter includes crushed *Aucella*. This specimen of *Virgatites*, 240 mm. in diameter (with two fragmentary specimens of a closely comparable form), superficially resembles the large Ammonite figured by Nikitin³ as *Perisphinctes martelli* Oppel, but which Siemiradzki⁴ considers to be an intermediate form between *P. martelli* and *P. orientalis* Siemiradzki. Large "*Perisphinctes*" of the group of *P. wartæ* Bukowski are recorded from beds that contain an early (Corallian) development of *Amæboceras* ("zone of *P. wartæ* and *Cardioceras alternans*" in Salfeld⁵), but the crushed example here discussed, with its *Aucella* (not radially marked), is a *Virgatites*,⁶ and not a Corallian "*Perisphinctes*", that is to say, it comes from above, not from below, the micaceous shales with *Amæboceras* cf. *nathorsti*.

The specimens of *Rasenia* apparently came out of nodules in the black shales, and since Salfeld⁷ records *Amæboceras kitchini* from the zone of *Rasenia cymadoce*, it is possible that they belong to the same horizon as the micaceous shales with *Amæboceras* cf. *nathorsti*. The specimens are not very well preserved, and there does not seem to be a very close resemblance to the common Market Rasen species (*R. evoluta*, *involuta*, etc.). The example compared with de Loriol's figure of *R. trimera*,⁸ with a diameter of about 150 mm., exceeds in size the form of *Rasenia* figured by Quenstedt⁹ as *A. cf. trifurcatus* Zieten.

¹ A comparable specimen in the Reynolds Collection comes from Ulla Berg, North Side of Van Keulen's Bay, Bell Sound.

² "D. Amm. d. Unt. Wolga-Stufe": *Mém. Com. Géol. St. Pétr.*, vol. viii, No. 2, 1890, p. 121, pl. vii, fig. 2 only.

³ "Allg. Geol. Karte v. Russland, Blatt 71, Kostroma": *Mém. Com. Géol.*, vol. ii, No. 1, 1885, p. 125, pl. iii, fig. 14.

⁴ "Monogr. Beschreib. d. Amm. Gattung *Perisphinctes*": *Palæontographica*, vol. xlv, pts. iv, v, 1898-9, p. 269.

⁵ "Die Gliederung d. Ob. Jura in N.W. Europa, etc.": *N. Jb. f. Min.*, etc., Beil. Bd. 37, 1914, p. 129, and table i.

⁶ There is very good agreement with *Per. nikitini* Michalski (loc. cit., p. 232, pl. xiii, fig. 1), but the much larger outer whorl has the aspect of that of such gigantic forms as *Virgatites virgatus* (in Michalski, loc. cit., pl. iii, fig. 1) or of "*Perisphinctes*" *losseni* Neumayr & Uhlig ("Ub. Ammonitid. a. d. Hilsbild. Norddeutschl.": *Palæontographica*, vol. xxvii, pts. iii-vi, 1881, p. 144, pl. xviii). The inner whorls characterize the latter as probably a *Polyptychites*, so that the resemblance of the outer whorl is only superficial.

⁷ Loc. cit., 1914, p. 129; also "Certain Upper Jurassic Strata of England": *Quart. Journ. Geol. Soc.*, vol. lxix, 1913, p. 423.

⁸ "Mon. Pal. z. à *A. tenuilabatus*, etc.": *Mem. Soc. Pal. Suisse*, vol. iii, 1876, p. 86, pl. xiii, fig. 13.

⁹ *Amm. d. Schwäb. Jura*, 1888, p. 998, pl. cxii, fig. 3.

The two forms of *Craspedites* are characterized by their compressed and almost smooth inner whorls, with a deep and comparatively small umbilicus. The outer whorl of the first example agrees very well with Nikitin's fig. 20,¹ and is just a little coarser in ornament, though not nearly so nodate as fig. 19, which, however, it equals in size. The other example resembles in its more sharply defined costation (of the outer whorl only) certain forms of *Craspedites* from the Rjasan horizon,² and the Neocomian *Tollia*, but it is quite different from the finely costate Valanginian forms from Northern Germany in the British Museum. The inner whorls of the type of those of a compressed *C. okensis* d'Orbigny sp.³ show this second form to belong to the Purbeckian *Craspedites*.⁴

Some fragments of belemnites, apparently from the Upper Jurassic beds of Cape Staratshin, seem to be referable to *Piesetrobelus magnificus* (d'Orbigny) in Pavlow.⁵

III. CRETACEOUS.

The only Ammonite in the collections from Green Harbour, a fairly well-preserved specimen of

Polyptychites sp. nov. cf. *suessi* Koenen, indicates the presence of the lowest Cretaceous or Valanginian. The form differs from Koenen's type⁶ in having a deeper and more funnel-like umbilicus, and in the weakening of the costation on the outer whorl. *P. sphaericus* Koenen⁷ and *P. stubendorffi* (Schmidt) Pavlow⁸ also are somewhat similar. The loss of the costation on the outer whorl is reminiscent of such forms as *P. variisculptus* Pavlow⁹ and *P. sp.* (*Olcostephanus* cf. *triptychiformis* Nikitin et *syzranicus*

¹ Loc. cit., 1885, p. 133, pl. v, fig. 20.

² E.g. *C.* ["*Olcosteph.*"] *bidevexus* Bogoslowsky, "D. Rjasan Horizont, seine Fauna, etc.": *Mat. z. Geol. Russl.*, vol. xviii, 1897, p. 56, pl. iii, figs. 3, 4.

³ In Murchison, Verneuil, & Keyserling, *Géol. d. l. Russ. d'Europe*, etc., vol. ii, pt. iii, Pal., 1845, p. 439, pl. xxxiv, figs. 13-17. Tullberg ("Üb. Verstein. a. d. Aucellen-Schichten Novaja-Semljass": *Bihang till K. Svenska Vet.-Akad. Handl.*, vol. vi, 1881, No. 3, p. 7) records *Craspedites okensis* from Novaja-Zemlya, where *Amœboceras* also is found.

⁴ Salfeld ("Monogr. d. Gattg. *Ringsteadia*": *Palæontographica*, vol. lxii, pl. ii, 1917, pp. 73-4) points out that certain *Involuticeras* of a much lower horizon have been confused with *Craspedites* (e.g. by Burekhardt, 1906), but the boreal forms here described have no resemblance to the Southern *Involuticeras*. Their poor state of preservation, unfortunately, prevents exact comparison with the numerous similar *Craspedites* of the *subditus-plicomphalus* group in the Blake Collection.

⁵ *Argiles de Specton*, 1892, p. 44, pl. v (ii), figs. 1, 2; also Sibir. Sept., loc. cit., 1913, p. 16, pl. ii, fig. 4.

⁶ "Die *Polyptychites*-Arten d. Unt. Valangin.": *Abh. k. Preuss. Geol. Landesanst.*, N.F., Heft 59, 1909, p. 76, Atlas pl. xii, figs. 2, 3.

⁷ "Die Ammonitid. d. Nordd. Neoc.": *Abh. k. Preuss. Geol. Landesanst.*, N.F., vol. xxiv, 1902, p. 122, pl. iv, fig. 1 only. This, however, belongs to a higher zone and the suture-line is different.

⁸ "Les Céph. d. Jura et du Crét. Inf. d. l. Sibir. Sept.": *Res. Scient. d. l'Exp. Pol. Russ.*, 1901-3, Sect. C; "Geol. & Pal., Livr. 4": *Mém. Acad. Imp. Sci. St. Pétr.*, ser. VIII, vol. xxi, No. 4, p. 29, pl. vi, fig. 1.

⁹ *Ib.*, p. 19, pl. iii, fig. 2.

Pavlov) in Bogoslawsky,¹ both of which, however, have a wider and less funnel-like umbilicus. The suture-line is characterized by four saddles between the siphonal line and the umbilical tubercle, the third of which (second lateral) is deeply bifid.

The matrix of this specimen is a very dark and hard limestone; but a fragmentary specimen preserved in a less calcareous rock, that partly is a true clay-ironstone, probably belongs to beds of the same age. This was collected at Fastness Camp, Cape Staratshin, and on account of its association with the similarly preserved *Rasenia*, *Virgatites*, etc., the writer at first was inclined to put it into *Gravesia*, though the umbilical tubercles are not rounded, but sharp and comma-shaped, or into *Cadoceras*. The specimen, unfortunately, is fragmentary, and shows no trace of the suture-line, representing probably the body-chamber of a large form ($D = 150$ mm.), with the inner whorls poorly preserved in crystalline calcite.

The specimen may be compared with

Euryptychites cf. *gravesiformis* Pavlov,

especially the smooth form figured on pl. xi, figs. 2c, 3,² but it has a less depressed whorl section and thus a more rounded periphery. *Polyptychites tschekanovskii* Pavlov,³ on the other hand, is too compressed and too involute, and still costate at a large diameter. *P. senilis* Koenen⁴ and *P. solidus* Koenen⁵ show a somewhat similar smooth and fat outer whorl.

To judge by the two specimens mentioned, it would appear as though the Valanginian deposits were closely connected with the Purbeckian and Portlandian beds below, yielding *Craspedites* and *Virgatites*. The matrix of the specimens of *Euryptychites* and *Craspedites* is very similar and agrees with that of numerous *Aucella* of the group of *A. terebratuloides*. Other examples that appear to include the higher *A. keyserlingi* are "phosphatic".

On the other hand, the *Ditrupa* sandstones, with *Crioceras*, that may be as high as Aptian,⁶ clearly belong to another set of deposits. Stolley records clays, with concretions, and a very doubtful fragment of a *Garnieria* [= a Valanginian *Platylenticeras* ?] below a flaggy, grey sandstone of the Flysch facies, with interbedded clayey seams; further, a very doubtful *Polyptychites* or *Simbirskites* from the *Ditrupa* sandstones. A change of facies between Cape Staratshin and Green Harbour on the one hand, and Advent Bay on the other, is, of course, possible, but the writer would refer all the Ammonites

¹ "Mat. z. Kenntn. d. Untercret. Amm. Fauna v. Centr. und N. Russl.": *Mém. Com. Géol.*, n.s., Livr. 2, 1902, p. 140, pl. xvii, fig. 1.

² Loc. cit. (Sibir. Sept.), 1913, p. 37.

³ *Ib.*, p. 34, pl. viii.

⁴ Loc. cit., 1909, p. 50, pl. xx, figs. 1, 5.

⁵ *Ib.*, p. 52, pl. xxii, figs. 1, 2.

⁶ Stolley, "Üb. d. Kreideform. und ihre Fossil. auf Spitzbergen": *K. Svenska Vet.-Akad. Handl.*, vol. xlvii, No. 11, 1912, pp. 10-12.

in the collection that come from Bunting Bluff, Advent Bay, to the Albian.¹ The specimens are extremely poorly preserved in a purple or brown, ferruginous sandstone, and associated with *Panopæa* of the type of *P. plicata*, a small smooth *Pecten*, etc. They are referred to :—

Sonneratia ? sp. cf. "*Hoplites*" *jachromensis* (Nikitin).²

„ ? sp. cf. *latisulcata*, Sinzow.³

„ ? (*Hoplites*?) spp. ind.

Cleoniceras ? cf. *bicurvatoides* Sinzow sp.⁴

Pompeckj⁵ recorded "*Virgatites*-like" Ammonites, resembling the Albian *Hoplites jachromensis* Nikitin, from a sandstone (*Dentalium* beds) of the Fyrkanten Berg ; but on account of the bad state of preservation of the fossils he could not assign a more definite horizon to them than "Portlandian (Lower Cretaceous)", with possibly the Albian included. It is matter for regret that the species here recorded are equally unsatisfactory, but they certainly seem to be nearer to Albian forms than to those of any other stage. It may also be added that they had already been referred to "*Hoplites*" in the field.

A comparatively well-preserved but small fragment of the body-chamber of an Ammonite similar to the first form recorded in the above list was collected by Mr. W. J. Reynolds this summer (1920) at Whale's Head. It is comparable with the form figured by Bogoslawsky from the "*dentatus* zone" of the Albian, but not identical with Sinzow's *Sonneratia jachromensis*.⁶

Stolley⁷ thinks it possible that the hundreds of feet of sandstones, between the *Ditrupa* (= "*Dentalium*") beds, with *Crioceras* and the Tertiary strata, may include the Gault and the whole of the Upper Cretaceous ; but the apparent gaps and certain doubtful plant-bearing beds make a re-examination of the whole of the Cretaceous succession very desirable.

In conclusion, the writer would like to express his indebtedness to those who have kindly assisted him in the examination of this fauna, namely, to Dr. A. Smith Woodward, F.R.S., and to Dr. C. W. Andrews, F.R.S., for their help in connexion with the fish and amphibian remains, to Mr. W. J. Reynolds for his ready assistance with stratigraphical information, and to Professor J. W. Gregory, F.R.S., for his continued help and interest in the preparation of this paper.

¹ The writer is unable to assign these specimens to any bed of Professor Gregory's succession.

² In Bogoslawsky, loc. cit., 1902, p. 128, pl. vi, fig. 4.

³ "Beitr. z. Kenntn. d. südruss. Apt. und Alb.": *Verh. Russ. Kais. Min. Ges. zu St. Pet.*, ser. II, vol. xlvii, 1909, p. 31, pl. ii, figs. 27-9.

⁴ *Ib.*, p. 29, pl. ii, figs. 7-18.

⁵ In Nathorst, loc. cit., p. 1500.

⁶ "Untersuch. Ammonit. Unt. Gault Mangyschlaks und Kaukasus": *Verh. Russ. Kais. Min. Ges.*, ser. II, vol. xlv, 1907, p. 473, pl. iii, figs. 9-13.

⁷ Loc. cit., p. 12.

The Use of Graphs in Palæontology

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GRAPHIC methods for the comparative study of numerous observations and facts have long been in use in the exact sciences. They have also been used to some extent in those branches of the descriptive sciences which deal more particularly with the problems of heredity and variation. The purpose of the present paper is to sketch in outline a way in which they may be used in the morphological and systematic study of fossils.

It is necessary at the outset to recall the precise nature of the material with which the palæontologist has to deal. In studying living organisms it is customary to think in terms of species, genera, and the like, either individually or distributed in space. This is the practice also in the study of fossils, but in this case the element of time must also be taken into account. The palæontologist consequently pictures species as merely members of a long, probably continuous, series, which he calls a line of descent or a lineage. He is fortunate indeed if his collection of specimens is so complete that he is able to reconstruct such a lineage in all its stages. Even when he has done this with the best fossil material available, the fact remains that his results are based upon incomplete evidence ; for all the softer parts of the animal—the nervous system, musculature, vascular system—perished long ago. Even the hard parts which are preserved for his use are frequently fragmentary, and consist merely of a bone, a spine, a thecal plate, or a spicule. To these he may give generic and specific names, which have a use and value ; but it must not be forgotten that such fragments cannot constitute a species, they are only a few of the many structures which together make up a species. Names or no names, the palæontologist is usually concerned with isolated or small groups of structural elements, or units, and never with the complete animal.

All this may seem trite ; but it is necessary to remind ourselves occasionally that our so-called lineages are usually little more than studies in series of changes undergone by a small proportion of the structural units which make up the living organism, and that absolute phylogeny is an almost unattainable ideal. The greater the number of units studied, the closer will be the approach to a true conception of the lineage, or line of descent, of the species, and therefore to the realization of the ideal.

The ever-accumulating fossil material makes it increasingly difficult to keep in mind all the peculiarities exhibited by each structure in all the genera, species, and varieties with which the investigator has to deal. For this and other reasons it seems desirable to seek for some method of expressing the morphological features of several types concisely, and in such a way that their evolutionary significance may be easily grasped. In setting forth

suggestions for such a method it will be necessary, first of all, to give some account of the principles which underlie a suitable method. This will be followed by several examples illustrating the application of the method. Finally, sundry thoughts suggested by these examples will be discussed.

STRUCTURAL ELEMENTS AND FLOW LINES OF CHANGE.

No one can study the anatomy and development of several types of allied organisms, living or extinct, without realizing that they consist of various parts, each of which, whilst it is correlated with the others, undergoes changes and modifications that are peculiarly its own. Such parts may be referred to as structural elements or units. In a broad sense they may be anything from a single cell to a complete organism, from a cell that becomes a muscle fibre, to a tadpole that becomes a frog. In the narrower sense in which the term is used in this paper they may include any relatively simple part, as a digit; or relatively complex part, as the whole limb of a vertebrate; a single segment, or the whole glabella or pygidium of a trilobite.

The term organ is not synonymous with structural unit. An organ such as the eye, or fin, may be treated as one structural unit, or as consisting of several units, according to the object of the particular inquiry.

When a structural unit is followed through the life-history of an organism, it is seen to undergo a series of changes, which is usually described as its course of development. If, on the other hand, it be examined in a number of more or less closely allied genera and species, which are either contemporaneous or follow one another in time, it is found to exhibit a series of conditions often strikingly like those which are seen at different stages in development.

By such developmental and comparative studies it is possible to reconstruct the series of changes to which any given unit is subject. The problem is analogous to that of the stratigraphical geologist seeking to work out the sequence of the rocks. A complete and unbroken sequence in one exposure is as rare as a similarly perfect lineage in a museum. He must therefore attain his end by piecing together the information obtained from several exposures. So, likewise, the palæontologist may discover the sequence of changes experienced by individual structural units by piecing together fragments of information obtained by the comparison of allied forms, and from portions of imperfectly known lines of descent. An illustration will perhaps make this clearer.

A comparison of a large number of palæozoic echinoids¹ reveals the fact that the ambulacral plates assume various shapes. When these are placed side by side they can be arranged to form a series of which several steps are shown in Fig. 1, I-III. A further series can be recognized which follows the lines of an increase in the number

¹ R. T. Jackson, *Mem. Bost. Soc. Nat. Hist.*, 1912.

of plates in a transverse row (Fig. 1, IV-VII). Is this seriation merely due to the ingenuity of the human mind, or does it represent a series of changes which the plates may actually undergo in evolution? The following strands of evidence taken together create a presumption that the latter is the true explanation.

(1) While plates like I occur as early as the Ordovician, others do not become manifest until a later date. Presumably, therefore, this is the most primitive condition.

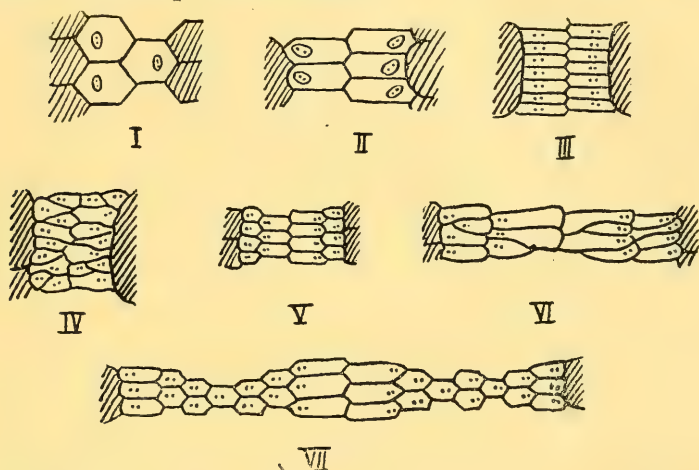


FIG. 1.—The ambulacral plates of various Palaeozoic echinoids: I, *Bothriocidaridaris*; II, *Hyattechinus*; III, *Lepidocentrus*; IV, *Lepidocidaridaris*; V, *Lovenechinus*; VI, *Oligoporus*; VII, *Lepidesthes* (after Jackson).

(2) Plates like those shown in III, for example, are not confined to forms which are closely allied, but also occur in forms which are distantly related. They are, therefore, not peculiar to any one particular line of descent.

(3) Among closely related forms some may show shape II, some shape III, and others such conditions as IV-VI, etc. Evidently a number of steps in the series may occur within the narrow limits of a few closely allied lines of descent.

(4) Some of the modern echinoids exhibit in early development plates like I, which at later stages become like III.

(5) Two or more shapes of plate, and any number from two to twenty, may be present in different parts of an ambulacrum of the same individual.

These last two facts indicate that some or all of these shapes may occur in the same line of descent. In a similar way the direction of change in structural units of any group of organisms may be traced.¹

Such structural units, and the directions of change they follow,

¹ See Osborn, *Amer. Naturalist*, 1917, p. 449 et seq. For full discussion of separability of units of organic structure.

provide the framework both for verbal description and for graphic representation.

In any series of changes thus elucidated the range is limited in extent and lies between two extremes, which may be usually ascertained for any group of organisms. Thus the number of plates in a transverse row of ambulacrum is not known to be less than two or more than twenty. The extreme range of shape, moreover, does not normally extend beyond the limits depicted in Fig. 1, I and III. There may be special groups, such as irregular echinoids, in which the modification of these plates may be carried to greater extremes. But even among them the range is limited. This is true also for the structural units in any group of organisms, as well for the number of toes or of teeth or the pattern of the dental crown in mammals, as for the degree of coiling or complexity of suture line in ammonites. In all the great orders, as in the Echinoids, there are special groups in which the range for any one structure may be excessive, as, for example, the teeth of the Proboscidea, and the suture line of the Pinacoceratidæ. But even in these cases the range will be found to have its limits.

Further, it must be remembered that, within the bounds of any group of allied forms, the number of directions of change for any particular structural unit is likewise limited. Numerical characters can only increase or decrease in number, coiling of a shell can only be in a plane or in a cork-screw spiral up to a certain height. This is merely putting the case for orthogenesis and rectigradation from the standpoint of individual structures, rather than from the standpoint of the organism as a whole. What is a variation in an organism is often merely another step in the serial change of a structural unit.

Hitherto the term structural unit has been used as though it always stood for something that was quite clear and precise. This, however, is not the case. Serial change may take place on a basis that is too vague and ill-defined for description as a structural unit. The ornamentation of an ammonite shell exhibits quite well-defined series of changes—but what is the structural unit which changes? Examples of this kind serve to emphasize the importance of thinking less statically and more dynamically, less in terms of structures that are present or absent, and more in terms of characters that are changing.

MORPHOLOGICAL GRAPHS AND THEIR INTERPRETATION.

In order to explain the use of the principles just enunciated for the purposes of graphical representation, the unit series of changes recognizable in any type of organism may be represented by the capital letters, *A*, *B*, *C*, etc. Thus, in the illustration already taken from Palæozoic echinoids, the series of changes shown in Fig. 1, I–III, may be called *A*. The series showing increase in numbers of plates in a transverse row may be called *B*, and so on.

The steps in each series may be taken as they stand, or they may

be expressed as a percentage of the total possible range. In the latter case the extremes of each series are taken as 0 per cent and 100 per cent respectively. The former method will be illustrated later, only the latter will be used here.

These two items, the series as a whole and the percentage of change within each series, are placed along the co-ordinate (Fig. 2).

If in a specimen *a*, one of a group of organisms which is being studied, series *A* has advanced to 40 per cent of the possible range, *B* to 20 per cent, *C* to 60 per cent, *D* to 20 per cent, and *E* to 25 per cent, then the line *a* (Fig. 2, I) will represent the specimen *a*. Similarly the line *β* will represent the specimen *β*.

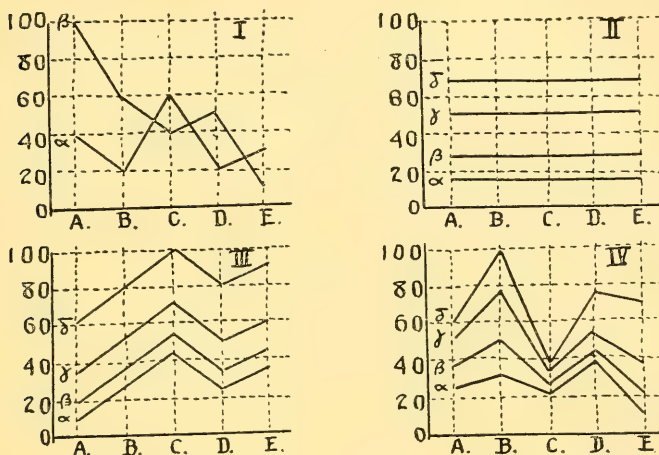


FIG. 2.—Diagrams illustrating the types of relationship that morphological graphs of organisms may have to one another.

Considering first a group of organisms belonging to the same lineage, two hypothetical cases may be taken :—

Case 1.—In this the rate of change is the same for all series. This implies that the series are intimately related with one another, so that the amount of change in one is, of necessity, accompanied by a proportional amount of change in each of the others. In this case the graphs, representing members of the lineage, will be parallel with one another. If each series started at zero, or at the same percentage level, then the graphs would be straight (Fig. 2, II). If each had its own starting point, the graphs would be crooked (Fig. 2, III).

Case 2.—In this the rate of change is different for the several series. This implies that the series are to some extent independent of one another, and not intimately correlated. The graphs, though they will not be parallel with one another, will develop out of, and will not cross one another (Fig. 2, IV).

Considering next a group of organisms which includes representatives of two or more lineages, only one case seems conceivable, viz. the one in which the rate of change is different for the several series. If the different series were so intimately correlated, that no change could take place in one without involving all the others in an equal amount of change, the members of one line of descent would be indistinguishable from those of another. As a matter of fact, even when there is striking homœomorphy, the members of the different lineages can still be sorted out from one another. This is because one lineage differs from another in the rate of change in one or more homologous structural units. In this case the graphs, representing several individual organisms, will not develop out of one another; on the contrary, they will cross one another (Fig. 2, I).

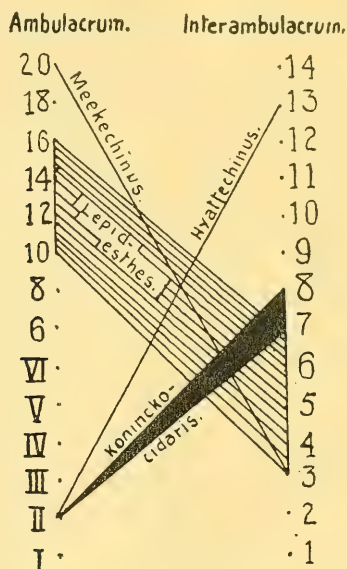


FIG. 3.—Graphic representation of some of the differences existing between several genera of Palæozoic echinoids. The Roman numerals I-VI stand for the drawings having the same numbers in Fig. 1. The Arabic number 14 in the left column stands for drawing number VII.

EXAMPLES OF GRAPHICAL REPRESENTATION.

To illustrate the application of the methods just described to the graphical representation of fossils, four examples will now be taken. For the first the facts already drawn from the Palæozoic echinoids will be used. In this case the facts will be taken as they stand without reducing them to percentages of possible change. The other three will be taken from Carboniferous corals. In these the facts will consist mainly of measurements, and will be expressed in the form of percentages.

EXAMPLE I: THE PALÆOZOIC ECHINOIDS.

The systematist finds that the changes which take place in the ambulacral and interambulacral areas in Palæozoic echinoids are of great importance for his purpose. As already seen, in the ambulacral area the plates pass through changes of shape varying from that shown in I to that at III in Fig. 1. Further change consists in an increase in the number of plates in a transverse row from two up to twenty. The transition from two to four plates is shown at IV in Fig. 1. A similar transition from four to six plates is shown at VI in Fig. 1. It is thus that the increase referred to takes place. In the interambulacral area the number of plates in a transverse row varies from one up to fourteen. Other changes take place in Palæozoic echinoids, but these will serve to illustrate the way in which graphical methods may be used for visualizing evolutionary phenomena. By placing the figures representing these directions and series of changes in the two areas in two vertical columns (Fig. 3), they may be used for graphical purposes.

According to the systematists' description, the genus *Hyattechinus* has two plates in a transverse row in the ambulacrum, and these are of the shape depicted in Fig. 1, II. In the interambulacrum it has as many as thirteen plates in the transverse row near the greatest circumference. The line II-13 in Fig. 3, therefore, represents *Hyattechinus*. The shaded area 10/16-3/7 represents *Lepidesthes*. Similarly the graphs II-7/8, and 20-3, represent two other genera.

With such a diagram it is easy even for a beginner to grasp at a glance some of the vital principles by which, consciously or unconsciously, the systematists have been guided.

The mere possibility of making two such columns of symbols indicates that the direction of change is not indefinite, but definite.

The graphs show that the combination of stages in the development of structural units may be quite different in separate though related genera. Putting the same fact from another point of view, one genus differs from another in the combination, not only of structural units, but of stages in the development of those units.

Further, if it be assumed that some or all of the genera represented in Fig. 3 had a common ancestor, having as its graph I-1 or II-2, it is evident that the rate of change in homologous structures has not been the same during the evolution of these genera. Had it been the same, had the changes in the ambulacrum been of necessity accompanied by similar and equal changes in the interambulacrum, then the descendants of that ancestor would have been represented by a series of parallel graphs, e.g. III-3, VI-6, 14-11, and so on. Divergent lines of descent like those represented by II-13 and 20-3 would thus have been impossible. The fact that the graphs are not parallel, but tilt this way and that, and that such divergent lines of descent are recognizable, proves that the two series of changes are not immutably bound up the one with the other; and that the rate of change along different directions varies in one line of descent,

being practically stationary in one and progressing rapidly in another. (Cf. II-7/8 with II-13.) On the other hand, in different lines of descent, homologous structures may progress at different rates (cf. the ambulacral end of each of the four graphs).

Such considerations as these indicate that whilst a genus, species, or variety is characterized by a combination of structural elements at certain stages of development, a lineage, or line of descent, is characterized by a certain cluster of directions and rates of change.

(*To be continued.*)

A Hypothesis of Mountain Building

By A. J. BULL, M.Sc., F.Inst.P., F.G.S.

THE following paper is an attempt to contribute to the solution of the problem of mountain building. It is here suggested that the folding of mountain ranges may be produced by the frictional drag of moving portions of the asthenosphere, and that these movements may be convective and result from its unequal heating by radio-active elements.

The earth is gaining heat energy from the breaking up of radio-active molecules and the liberation of some of the energy of these heavy elements in the form of heat. It is at the same time losing heat by conduction through the crust and subsequent radiation. Now, it has not been possible to equate these two quantities, the average quantity of radium found in rocks by Strutt being many times greater than that necessary to make good the loss by radiation into space. This disagreement, which is doubtless due to causes not yet ascertained, does not in any way invalidate the established facts that the earth is both gaining and losing heat.

The author is aware that many geologists have attempted to explain mountain building in terms of a cooling and contracting earth, but were such the case the contraction must have been continuous and progressive with no periods of complete rest, with the result that the whole crust would be in compression, whereas the most characteristic phenomena of the throwing up of mountain chains are that they are *local in place and occasional in time*. More recently this hypothesis has been modified by supposing that the contraction only takes place at long intervals, and is due possibly to molecular rearrangement in the interior.

In addition to this "curiously local distribution of . . . compression", as Oldham has called it, it must be remembered that the most intense compression and folding occurs in the centre of a mountain range, and that the folding becomes less on the outskirts. It has several times happened that the upheaval has affected freshly deposited material and has followed a long period of sinking, e.g. Malvernian, Armorican, and Alpine foldings. In contrast to the folded districts large portions of the crust have been but little

disturbed for long ages, normal faulting possibly indicating a state of slight tension. The phenomena of fissure eruptions indicates that parts of the crust have been in considerable tension, which is further borne out by the wide evidence Professor J. W. Gregory has gathered that fiords are tension clefts and rift valleys. It would be out of place to enlarge on this aspect of the matter, but I desire to indicate that geological evidence does not readily support the hypothesis of a contracting earth.

The theory of isostatic adjustment may be regarded as well authenticated from the work of Barrell in the United States and Oldham in India. The tendency to this adjustment must follow as a consequence of the simple principles of hydrostatics once it is conceded that there underlies the crust material that will flow under long-continued, but not necessarily great, stresses; on the other hand, the completeness of such an adjustment must be conditioned by the strength of the crust to resist distortion.

It is evident from the many types of igneous rock that are met with on the surface that the interior of the earth cannot be homogeneous in composition, hence it may be assumed that radioactive elements are not evenly distributed, and that where they exist in greater quantity there will result local heating. Now, where this occurs between the crust and the Hayford compensation level, the result could be that portions of the crust might be elevated considerably in relation to the crust above the lesser heated regions. There is evidence that the change of density in the lower parts of the crust might be greater than that produced by mere thermal expansion, for instance, the density of one mode of a particular rock has been shown by Dr. L. L. Fermor to differ from that of its norm by as much as twenty per cent, so that the slow melting of such a rock might easily produce a considerable change of density. Such density differences might continue to increase during long periods of time during which material would be removed by denudation from the elevated tracts and deposited in the relatively depressed tracts, causing these to sink still lower, as has been the case in the Gangetic trough. These conditions might be terminated by a convective movement, which would in a comparatively short time establish more stable conditions under the crust. A movement of this kind occurring in one place might well start movements in adjoining districts where unstable conditions had been attained, and so the convective movements might spread until they became world-wide. The effect of such movements would be to act as a drag on the under surface of the crust, drawing out the lower portions into schists and gneisses and disrupting the upper portion as it was moved. This would be most marked in the lower layers of the crust. These would be dragged into folds and puckered, while the higher layers would not be so much affected. The gaps thus formed in the lower strata would be filled by molten material from below, which might reach the surface in places.

Should a relatively cooler portion of the asthenosphere be situated between two hotter portions, all being at about the same level, then, when movement commenced, there would be two opposing currents dragging the under surface of the crust, which would be crumpled along a line perpendicular to the currents. There would thus arise a line of folding above the region where the asthenosphere was sinking, and the crust outside the moving regions would be in tension. Now the folded mass, being lighter than the asthenosphere, would float in it and project above the general level of the crust. It would thus be a mountain chain with light roots, and denudation of the protruding mass would cause a further rise, for as many of the cracks and folds would be approximately vertical, isostatic adjustment would be relatively easy, because the broken crust would have little strength, and this might continue until denudation had removed the mountain chain and only traces remained, as in Devonshire.

Away from the centre of folding, the underdrag of the slowly moving material would make its effects felt in various ways. Where there existed old lines of folding there would be a tendency to accentuate these, and to increase any want of symmetry, the steeper limbs of the anticlines indicating the direction of approach. For instance, the Weald, Purbeck, and Ridgeway anticlines have their steepest dips on the north or north-west, being in agreement with the idea of an undercurrent from north to south, i.e. towards the Alpine axis of folding. The effect of the underdrag on rocks that were brittle and without a thick cover might well produce movements along numerous slide planes, such as have occurred in Scandinavia.

In this connexion I desire to draw attention to a remark made by Mr. Bernard Smith before the Geological Society on the 23rd June, 1920, to the effect that he and Mr. C. B. Wedd had come to the conclusion that certain structures in North Wales had been produced by the deeper seated rocks moving first and dragging those above.

This hypothesis furnishes a possible explanation of the following:—

(a) The intense folding of mountains along well-defined lines while rocks sometimes at no great distance show no indication of compression, and also the fact that the lower beds are usually more distorted than the upper.

(b) The folding often follows a long period of deposition.

(c) Old axes of folding or "lines of weakness" are often accentuated.

(d) The formation of fiords and fissure eruptions.

(e) The change of type of magma erupted in a particular district after long geological intervals, as on the Peruvian coast and in the Great Rift Valley.

(f) The formation of gneisses and schists from plutonic and other rocks.

The hypothesis suggests a source or energy ample for the

mechanical work to be done, but its chief weakness is that it is not supported by sufficient evidence of tension in the crust flanking the lines of folding. For instance, there is evidence that the fissure eruptions of the North of Ireland and Scotland are of earlier date than the Alpine folding, and that the two did not take place concurrently, as is here suggested.

Whatever may be the main cause of earth movements, there are no doubt many minor causes which affect the results. It is possible, for instance, that the tidal waves in the crust which Michelson has shown by the use of his interferometer to attain a height of 2 or 3 feet, may determine the formation of north and south joints, especially in the tropics, and affect the edges of oceanic areas.

Fauna of the Brachiopod Beds at Cauldon, Staffs.

By W. E. ALKINS, M.Sc.

IN a recent note¹ Mr. J. Wilfrid Jackson, F.G.S., and the writer mentioned the occurrence at Cauldon, Staffordshire, of highly fossiliferous limestones, resembling those of the "Brachiopod-beds" of Castleton, Park Hill, Narrowdale, Thorpe Cloud, and other stations on the north-west, west, and south-west of the Staffordshire-Derbyshire limestone massif. It will perhaps be of interest to put on record the fauna of these beds, as far as it has yet been worked out, since the conditions under which they occur renders it highly improbable that any considerable amount of material will ever be available from them, and since they represent a phase which does not, so far as is known at present, occur to any extent in the more immediate neighbourhood of this station.

At the village of Cauldon, very pure and very fossiliferous soft white limestones have been found to occur at the east end of the churchyard, whence they extend some little distance south in the direction of the large quarry on Cauldon Low, as is shown by a small exposure in a field between the church and the Waterhouses Road. Unfortunately there are no large exposures of these beds, and the material on which this note is based has been obtained almost entirely from stone quarried out during the sinking of grave-shafts. At the west end of the churchyard the limestone is totally different in character; it is hard and slaty, and contains practically no fossils. The absence of sections renders obscure the relationship of these beds to each other, and also to the massive limestones of Cauldon Low itself, which appear to belong to a relatively low horizon—C-S₁. A noteworthy feature is the occurrence of many "pot-holes" in and about the churchyard.

According to the 1 inch Geological Survey map (72 N.E.), the limestone here is cut off from the Pendleside Series by faults on the north-west and north-east sides, but no faults are shown between Cauldon Low and Cauldon Church. The slight eminence on which the

¹ GEOL. MAG., Vol. LVI, 1919, p. 59.

church stands is formed by a block of limestone projecting from the main mass, and its structure is an interesting problem.

The fauna which has been obtained from these beds is given in the tables below. An attempt has been made to refer each species to a published figure, in the hope that this will increase the value of the lists. As is always the case, in studying a large suite of specimens from the brachiopod beds many forms cannot be matched against illustrations; to these no reference is made.

BRACHIOPODA.

(References to plates and figures without further remark are to Davidson's Monograph.¹)

- Dielasma hastatum* (Sow.). Pl. i, fig. 12.
Terebratula sacculus (Mart.). Pl. i, fig. 27.
T. vesicularis de Kon. Pl. ii, fig. 5.
Athyris expansa Phil. Pl. xvi, fig. 16.
A. lamellosa l'Eveille. Pl. xvi, fig. 1.
A. planosulcata Phil. Pl. xvi, figs. 2, 4, 5.
A. subtilita Hall. Pl. xvii, fig. 10.
Seminula globularis (Phil.). Pl. xvii, fig. 15.
Retzia radialis (Phil.). Pl. xvii, figs. 19, 20.
Spirifer bisulcatus Sow., var. *semicircularis* Phil. Pl. vi, figs. 1, 2.
Sp. bicarinatus McCoy. Pl. viii, fig. 18, exactly.
Sp. clathratus McCoy. Pl. iii, fig. 6.
Sp. duplicicosta Phil. Pl. iv, fig. 5.
Sp. grandicostatus McCoy. Pl. v, figs. 38, 39; pl. vii, figs. 8-11.
Sp. integricosta Phil. Pl. ix, fig. 16.
Sp. cf. paucicostatus McCoy. Pl. iv, fig. 12.
Sp. cf. pinguis Sow. Pl. x, fig. 7, but finer ribbing.
Sp. striatus (Mart.). Pl. ii, figs. 15, 16, exactly.
Sp. triangularis (Mart.). Pl. v, figs. 18-21.
Sp. triradialis Phil. Pl. ix, fig. 10.
Brachythyris rhomboidalis McCoy. Pl. xii, fig. 6.
Martinia glabra (Mart.). Pl. ix, figs. 3, 7; pl. xii, fig. 2.
Reticularia elliptica (Phil.). Pl. xiii, fig. 3.
R. lata (Brown). Pl. xii, fig. 1.
R. lineata (Mart.). Pl. xiii, figs. 4, 5, 6.
Rhynchonella trilatera de Kon. Pl. xxiv, figs. 24, 25.
Rhynchonella, sp. Pl. xix, figs. 9, 10 (dwarf).
Pugnax pleurodon (Phil.). Pl. xxiii, fig. 2.
P. pugnus (Mart.). Pl. xxii, fig. 4, but smaller.
Camarophoria crumena (Mart.). Pl. xxv, figs. 4, 5.
C. globulina, var. *rhomboida* (Phil.). Pl. xxiv, fig. 10.
C. rhomboida (Phil.). Pl. xxiv, figs. 11, 12.
C. seminula (Phil.). Pl. xxiv, figs. 13-16.
Camarophoria, sp. Pl. xxv, fig. 9, exactly.
Orthis keyserlingiana de Kon. Pl. xxviii, fig. 14.
Rhipidomella michelini (l'Eveille). Pl. xxx, figs. 8, 9.
Schizophoria resupinata (Mart.). Pl. xxix, fig. 2; pl. xxx, fig. 1.
Leptæna analoga Phil. Pl. xxviii.
Orthotetes crenistria (Phil.). Pl. xxvii, fig. 8.
Productus aculeatus (Mart.). Pl. xxxiii, figs. 16, 17.
Pr. concinnus Sow. Pl. xliii, figs. 9, 10.
Pr. cora d'Orb. Pl. xxxvi, fig. 4.
Pr. costatus Sow. Pl. xxxii, fig. 3, exactly.
Pr. elegans McCoy. Pl. xlv, fig. 15.

¹ T. Davidson, "British Carboniferous Brachiopoda": *Palæont. Soc., London*, 1857-62.

- Pr. fimbriatus* Sow. Pl. xxxiii, figs. 13, 14.
Pr. cf. fimbriatus (Sow.), Vaughan, *Quart. Journ. Geol. Soc.*, vol. lxii, 1906,
 pl. xxx, fig. 6
Pr. longispinus Sow. Pl. xxxv, fig. 8.
Pr. margaritaceus Phil. Pl. xlv, figs. 5, 8.
Pr. martini Sow. Pl. xliii, fig. 7; pl. lv, fig. 11.
Pr. mesolobus Phil. Pl. xxxi, figs. 7, 8.
Pr. plicatilis Sow. Pl. xxxi, fig. 3.
Pr. punctatus Mart. Pl. xlv, figs. 14, 18.
Pr. pustulosus Phil. Pl. xli, fig. 1.
Pr. scabriculus Mart. Pl. xlii, fig. 6.
Pr. semireticulatus Mart. Pl. xliii, fig. 1.
Pr. spinulosus Sow. Pl. xxxiv, figs. 18, 19.
Pr. youngianus Dav. Pl. xxxiii, figs. 21, 22.
Chonetes hardrensis Phil. Pl. xlvii, fig. 12.
Ch. papilionacea Phil. Pl. xlvi, figs. 3, 4; one specimen has the hinge-
 line four inches long.

LAMELLIBRANCHIATA.

(References to Hind's Monograph.¹)

- Posidoniella vetusta* Sow. Vol. i, pl. v, figs. 9–11.
Paralelodon bistriatus Portl. Pl. ix, figs. 5–12.
Edmondia accipiens Sow. Pl. xxxvii, figs. 8–16.
Leiopteria laminosa Phil. Vol. ii, pl. iii, figs. 4–9.
Eumicrotis hemisphaericus Phil. Pl. vii, figs. 1–6.
Pterinopecten tessellatus Phil. Pl. ix, figs. 8–11.
Pt. eximius de Kon. Pl. xi, figs. 13, 14.
Pt. dumontianus de Kon. Pl. xiv, figs. 1, 2.
Aviculopecten murchisoni McCoy. Pl. xiv, figs. 3–7.
A. interstitialis Phil. Pl. xiv, figs. 16–21.
A. clathratus McCoy. Pl. xv, figs. 1–6.
Pseudamysium concentrico-lineatum Hind. Pl. xx, figs. 7–10.
Ps. anisotum Phil. Pl. xxi, figs. 13–20.
Schizodus obovatus McCoy. Pl. xxiv, fig. 14.

TRILOBITA.

(References to Woodward's Monograph.²)

- Phillipsia derbiensis* Mart. Pl. i.
P. gemmulifera Phil. Pl. iii, fig. 5.
P. scabra H. Woodw. Pl. ix, fig. 5a.
Brachymetopus uralicus de Vern. Pl. viii, figs. 1–8.
Griffithides carringtonianus Eth. MS. Pl. ix, fig. 6a.

GASTROPODA.

- Patella ryckholtiana* de Kon. *Descr. An. Foss.*, 1842–44; pl. xxiii, fig. 5.
Capulus trilobus Phil. *Geol. Yorks.*, pl. xiv, figs. 12, 13.
Bellerophon costatus Sow. De Kon. (loc. supra cit.), pt. iv, pl. x, figs. 1–3.
B. tenuifascia Sow. De Kon. pt. iv, pl. xxxviii, figs. 8–10.
Phanerotinus nudus Sow. De Kon., pt. iv, pl. xxii, figs. 16–18.
Straparollus dionysii de Mont. De Kon., pt. iii, pl. xiv, figs. 16–18.
Str. pilopsideus Phil. De Kon., pt. iii, pl. xiv, figs. 22–24.

In addition there are several corals, of which *Cladochonus bacillaris* alone has been identified; *Chaetetes tumidus*, *Fenestellidæ*, and a number of unidentified Brachiopoda and Gastropoda.

The writer's thanks are due to Mr. J. Wilfrid Jackson for much very valuable assistance in the identification of species.

¹ W. Hind, "British Carboniferous Lamellibranchiata": *Palæont. Soc., London*, 1896–1905.

² H. Woodward, "British Carboniferous Trilobites": *Palæont. Soc., London*, 1883–4.

An Outline of Chinese Geology.

By J. S. LEE, M.Sc., Birmingham.

(Continued from p. 329.)

To the south of the Tsing-ling Range the above classification of the Sinian System no longer holds good. The Kisinling Limestone of western Hu-peh¹—a massive grey limestone grading downwards into a slaty limestone and slates—has yielded in its upper part gigantic *Orthoceras*, or the pagoda stone, and other Ordovician fossils; and is therefore regarded as equivalent to the upper and the middle part of the Sinian in north-east China. Unconformably underlying the Kisinling Limestone, a glacial deposit, the Nantou Tillite, was found by Willis and Blackwelder at Nan-tou, near the north-western entrance of the I-chang Gorge (about long. 111° 10' E., lat. 30° 45' N.). Mr. V. K. Ting has verbally informed the writer that this interesting deposit extends towards the south-west for a considerable distance. The occurrence of *Asaphus* and *Trinucleus* to the south of Ning-kiang (about long. 106° E., lat. 32° 45' N.) makes it highly probable that, there, the upper Sinian is exposed among other folded Palæozoic strata.²

Further south, in eastern Yun-nan, the Cambro-Ordovician rocks³ present an entirely different facies to that of north-east China. Nevertheless, they contain the same fauna, at least throughout the Cambrian formation. According to Dr. Deprat, the Ordovician there consists of sandstones, shales, and marls, and the Cambrian consists of an upper group of argillaceo-arenaceous rocks and a lower group of compact grits with intercalated limestone. A local stratigraphical break appears to exist between the Ordovician and Cambrian.

Loczy regards the limestone that occurs to the east of Pa-tang (about long. 99° E., lat. 30° N.), and its associated metamorphic strata, as a Sinian formation. Richthofen considered at one time or another three successive series of rocks as Sinian representatives in south-east China. They are:—

- c. Matsu Limestone. A dark-grey siliceous limestone containing sandy and clayey slates, hornstones, and calcite-veins. Typical exposure is found in the Matsu-shan, on the northern side of the Poyang-hu.
- b. Lushan Slate. Grey-green, fine-grained slates with characteristic quartz-veins which are often auriferous; typically occur in the Lu-shan, north of the Poyang-hu.

The Kauling Slate that occupies large areas in the provinces of Kiang-si and southern An-hwei is possibly identical with this series.

- a. Tahau Sandstone. Massive, quartzitic red sandstone forming the bulk of the Tahau-shan, south-east of Ta-tung, southern An-hwei.

It should be emphatically pointed out that both Loczy and Richthofen are unable to produce palæontological evidence for their

¹ Willis, op. cit., vol. i, pt. i, pp. 269–72.

² *China*, vol. ii, pp. 597–601.

³ Deprat, op. cit., 1re Partie, pp. 55–63.

determination of age. The black-brown crystalline limestone of Lun-shan¹ (about long. 119° 30' E., lat. 32° 5' N.), in the lower Yang-tze Valley, may, however, be assigned to the Sinian without any hesitation, for it contains abundant characteristic oolites and globulites, and several Ordovician species; further, it is overlain by a graptolite-bearing shale.

Having briefly referred to the distribution and successions of the Sinian rocks, we now proceed to interpret their significance. During the transitional period from the Wutai-Nankou Era to the early Cambrian time or the Manto epoch, the whole of northern China having been already eroded to a vast peneplain, gradually and uniformly came under the transgressive Sinian water. On the other hand, the south and the south-east of the country were then probably dominated by mountains or highlands from which presumably was derived the gritty material that forms the lower Cambrian beds in eastern Yun-nan. In central China little is known about the geographical distribution and the stratigraphical position of the Nantou Tillite. We are, as yet, unable to offer any solution to many interesting scientific problems: whether, for instance, such an early glaciation was due to the general lowering of temperature in northern and central China by some secular cause or due to the great elevation of land surface resulting from the post-Wutai-Nankou and pre-Cambrian movement; and whether the glaciation did really take place in the early Cambrian time as maintained by Willis and Blackwelder. For further research the similar cases in Norway and North America should be naturally brought to our comparative study.

The drowned ancient land continued to subside under the Sinian sea, leading to the deposition of finer and calcareous material. Palæontological evidence also points to the same effect. The Manto sea with its *Redlichia* fauna undoubtedly extended from Shan-tung, Yun-nan to the Punjab and Australia. There was little faunal communication with the western world. But soon after the commencement of the Middle Cambrian period the *Dorypyge* or the *Ptychoparia* fauna began to thrive. The Sinian sea by this stage was thrown open to free migration of organisms, and consequently swarmed with cosmopolitan forms of life. Walcott has demonstrated that the *Dorypyge* fauna of China is not only present in western North America, but associates with the *Paradoxides* fauna of north-west Europe.

Although the Sinian sea effected a sweeping transgression, the main ranges of the Tsing-ling and the Nan-shan region, however, stood above the water for the most part, if not the whole of the period. No rocks of demonstrable Sinian age have yet been found in these

¹ *China*, vol. iii, p. 718. The age of the Lunshan Limestone is undoubtedly discussed by Mr. V. K. Ting in a paper on "The Geology below Wu-hu", *Hwangpu Conservancy*, July or August, 1919, Shanghai. Unfortunately, the writer is unable to obtain the paper.

mountains. The intense folding that prevails in all parts of these ranges is certainly an excellent condition for the preservation of extensive strata if they were once present; and the peculiar lithology so widely prevalent with Sinian rocks, together with their highly fossiliferous nature, would form conspicuous landmarks that could not have escaped the notice of so many keen observers if the rocks were there.

From early Cambrian time to the end of the Ordovician period, or probably later, there was little alteration of the distribution of land and sea in China. The processes of denudation and deposition were allowed to continue their operation in a monotonous and undisturbed manner. Eastern Yun-nan is the only area that was in a relatively unstable condition. The intercalation of limestones in the lower gritty series, the grits in the upper argillaceous strata of the Cambrian formation, and the local unconformity between the Ordovician and Upper Cambrian are probably all due to the oscillation of the sea-floor. Igneous activity is practically unknown in China throughout the whole of the Sinian period.

THE SILURIAN AND DEVONIAN.

The results of geological researches and mining records hitherto obtained in northern China have conclusively shown that in this vast area the Sinian System is separated from the overlying Shansian coal-bearing rocks by an unconformity of great magnitude. Although the contact between the two is generally of concordant nature, the hiatus of life sequence proves the existence of an unconformity beyond any doubt. The top of the Sinian contains Ordovician fossils as already mentioned; near the base of the overlying Shansian System marine fossils have been found. Though the exact age indicated by these fossils is still a matter of dispute, they undoubtedly represent the life of a period not earlier than the Lower Carboniferous.

From these palæontological data it follows that Silurian and Devonian deposits are practically absent in northern China, namely, in the provinces of Manchuria, Shan-tung, Chi-li, Shan-si, Ho-nan, and probably Shen-si. Either during the whole of these periods or a part or parts of them these provinces must have been subjected to uniform erosion, consequent to a broad epeirogenic movement.

Lorenz speaks of Upper Devonian transgression¹ in Shan-tung on account of the presence of a series of coarse strata having a maximum thickness of not more than 300 feet. These rocks lie between the eroded Sinian limestone and a fossiliferous zone which is doubtfully assigned by Professor Frech to the Lower Carboniferous. In the absence of further evidence it would appear risky to accept Lorenz's hypothesis.

¹ Lorenz, "Beitrag z. Geol. u. Pal. von Ostasien, etc.": *Zeits. d. d. Geol. Gesell.*, vol. lvii, pp. 448-50.

From the Nan-shan Ranges Obrutchev reports the occurrence of fossiliferous Devonian generally consisting of a series of red and green sandstones and slates being occasionally underlain by a limestone which is also assigned to the Devonian; and Silurian (?) consisting of highly metamorphosed strata such as quartzite, crystalline limestone, and even schist.¹

In the western Tsing-ling to the north of Liu-pa (about long. 107° E., lat. 33° 40' N.) Richthofen found a mighty sequence of limestone and sandstone apparently folded in an anticline. He maps them as "Silurian and Devonian".²

Silurian and Devonian fossils³ have been found at many localities in the mountains bordering the northern and western sides of the Great Red Basin of Su-chuan. It appears that a continuous belt of marine Siluro-Devonian formation runs along the north-west side of the Red Basin. The Devonian, on the western side of the basin, seems to rest unconformably upon the older rocks; but merges as a rule into the Lower Carboniferous without any break.

To the east of the Great Red Basin or in the western part of Hu-peh, Willis and Blackwelder distinguish a Sintan Formation⁴ chiefly composed of a green shale being conformably underlain by the Kisinling Limestone of Sinian age, and conformably overlain by the Wushan Limestone of Carboniferous age. The occurrence of this series of shale in the Yang-tze gorges is also reported by Richthofen,⁵ Abendanon,⁶ and others.⁷ Abendanon holds that the Sintan Formation underlies the Kisinling Limestone. This, however, does not appear to be the case. It is quite possible that the argillaceous series in the lower part of the Kisinling Limestone may have locally developed to a shaly facies resembling the Sintan series. Hence there arose the dispute. By a feasible argument which we need not discuss here, Willis and Blackwelder assign the Sintan Formation to the Siluro-Devonian period. What deserves our attention in this connexion is the occurrence of a thick series of green shale among the Siluro-Devonian strata exposed near the Ning-kiang district further west. According to Richthofen's description this shale is lithologically similar to the Sintan rocks.

In the lower Yang-tze Valley, apart from the limestones and the graptolite-bearing shale of the Lun-shan, west-south-west of Chin-kiang, we do not hear of the occurrence of demonstrable Silurian rocks. Of the Devonian, Kingsmill and Richthofen describe

¹ C. Diener, "Die wichtigsten geogr. u. geol. Ergeb. d. Reisen Obrutschews in zentralen u. westlichen Nanschan": *Peter. Mitt.*, vol. xlviii, 1902, pp. 97-106.

² *China*, vol. ii, pp. 582-4, Tafel vii; Atlas Erste Abt. Tafel 24.

³ Loczy, op. cit., vol. i, pp. 432-5, 682-3; vol. iii, p. 22 et seq. *China*, vol. ii, pp. 595-601; vol. iv, pp. 37-102. *Journ. Geol. Soc. Tokyo*, 1915, No. 261, pp. 64, 67; No. 263, p. 87.

⁴ Willis, op. cit., vol. i, pt. i, pp. 273-4.

⁵ *China*, vol. iii, pp. 106-8.

⁶ Abendanon, "Die geol. d. Roten Beckens": *Zeits. d. d. geol. Gesell.*, vol. lix, pp. 197-203; *Journ. Geol. Chicago*, vol. xvi, pp. 588-616.

⁷ Noda, *Bull. Imp. Jap. Geol. Surv.*, vol. xxv, No. 1, 1915, p. 67.

two series or two facies of deposits: ¹ the one is a semicrystalline, siliceous dolomite such as those exposed in the vicinity of Kiu-kiang (about long. 116° E., lat. 29° 45' N.), in the Tung-ting-shan of the Tai-hu, southern Kiang-su, and in the hills between Nan-king and Chin-kiang. The other is a group of quartzitic sandstones and conglomerates such as those exposed in the Lu-shan, north-west of the Poyang-hu, Kiang-si; in the Hsiau-hau-shan, Tung-kwan-shan, and Tung-lu-hsien, southern An-hwei. The relation between these two series or facies is altogether obscure at present. Richthofen's report from the Hwa-shan, between Nan-king and Chin-kiang, and Kingsmill's report from near the Tai-hu, however, seem to agree in showing that the dolomitic limestone overlies the sandstone group. On the other hand, in the Hsi-bsia-shan, east of Nan-king, the sandstone group is directly overlain by a marine formation of Lower Carboniferous age. The lack of direct palæontological evidence inevitably invites much doubt as to the true age of these rocks.

In contrast to northern China, namely, the part north of the Tsing-ling Range, the Devonian formation is well developed in the south-western provinces, that is in Hun-nan, Kwang-si, Kwei-chou,² and Yun-nan. It generally consists of a highly fossiliferous marine limestone with or without the intercalation of shaly strata, and contains a fauna intimately related to the marine Devonian fauna of Europe. To demonstrate this close faunal affinity, nothing would be more emphatic than pointing out the occurrence in the Chinese Devonian of such familiar characteristic forms as *Spirifer curvatus*, *S. verneuili*, *S. undiferus*, *Atrypa reticularis*, *A. aspera*, *Rhynchonella* (*Pugnax*) *pugnax*, *Productella subaculeata*, *Uncites gryphus*, *Chonetes orientalis*, *Cyathophyllum cæspitosum*, *C. roemeri*, *Favosites sphaericus*, *Calceola sandulina*, *Alveolites*, *Aulopora*, etc.

Among the south-western provinces Devonian as well as Silurian is best known in Yun-nan. Loczy years ago observed in western Yun-nan a Silurian limestone containing characteristic large Cystidian plates.³ Recently Dr. Deprat found in eastern Yun-nan, a series of argillaceous sandstones yielding Silurian fossils, and argillaceous limestones with abundant Devonian fossils. Though the Devonian formation is somewhat variable in its lithological

¹ *China*, vol. ii, pp. 559, 562, 722, 730, 741. Kingsmill, "Note on some outlying Coal-field, etc.": *Brit. Roy. Asiat. Soc. N. China Br.*, ser. II, No. 111, pp. 102-3.

² Frech, "Ein neues Vorkommen des Stringocephaln-Kalk in Hu-nan": *Centralbl. f. M.G.*, N.C. 7, 1914. Davidson, *Quart. Journ. Geol. Soc.*, vol. xxii, 1853, pp. 353-9. Leclère, *op. cit.*, p. 26. Douville, *C.R. Acad. Sci. Paris*, vol. cxxx, pp. 592-5; *idem*, vol. cxi, pp. 692-4.

³ Loczy, *op. cit.*, vol. i, p. 767; *idem*, vol. iii, p. 21. F. A. Bather discusses the structure of the Cystidea from Yun-nan in some details (*GEOL. MAG.*, Dec. VI, Vol. V, No. 11, 1918); F. R. Cowper Reed describes several species of Cystidea in the Ordovician and Silurian faunas from western Yun-nan, which include, according to Miss Elles, a number of species of Llandovery Graptolites (*Palaeont. Indica*, N.S., vol. vi, No. 3, 1917).

character, the faunistic zones, which are no less than eighteen in number as established by Deprat,¹ persist throughout a wide area.

The Devonian formation is separated at many localities in the region of eastern Yun-nan, Kwang-si, and Kwei-chou from the older rocks by an unconformity. The occurrence of *Spirifer tonkinensis* in the Nan-ti district, south of the provincial capital of Yun-nan, has, however, led Deprat to assert the presence of transitional beds from the Silurian to the Devonian. The Upper Devonian passes into the Lower Carboniferous in perfect conformity throughout the south-western provinces.

Now let us examine the facts so far described from a historical point of view. In the latter part of the Sinian time, namely, the Bala or Llandovery epoch, the whole of northern China was still under the cover of a vast ocean. The Nan-shan and the Tsing-ling Ranges that stood out from the early Sinian water were by this time at least partially submerged. The early Silurian sea evidently extended from northern China to the south-west covering the present Yang-tze Valley, either the whole or the western part of Su-chuan, the greater part of Yun-nan, and farther spread itself out towards the direction of Indo-China, Burma, and beyond. This sea was undoubtedly but a part of the great Silurian ocean that extended over the present Eurasian Continent and North America, for Richthofen, in journeying from Ning-kiang to Tschau-tien, found in highly fossiliferous limestones a colony of widely distributed Silurian corals, together with a number of cosmopolitan Brachiopods, such as *Favosites*, *Halysites*, *Heliolites*, *Amplexus*, *Orthis calligramma*, *Spirifer radiatus*, *Leptæna sericea*, *Strophomena corrugatella*. The continent during the Silurian time lay in the south-east of the country.

On the close of the Silurian period a general earth-movement took place in Asia involving at least the south-western provinces of China Proper. The nature of the movement was not intensive and temporary, but extensive and lasting. As southern China was undergoing progressive subsidence, the Lower and the Middle Devonian sea gradually advanced towards the north-east. The pre-Devonian land in the provinces of Kwei-chou, Kwang-si, and probably Hu-nan was consequently submerged.

What, then, had happened to northern China while the subsidence was going on in the south? Richthofen is of the opinion that during the Devonian time northern China was under an abysmal ocean in which very little material was deposited.² We need not raise all the difficulties that such a hypothesis has to encounter. Tectonic consideration alone seems sufficient for the solution of this problem. In view of the fact that an anticline or an anticlinorium is generally accompanied by a syncline or a synclinorium, and vice versa, might we not expect a broad, slow upheaval of land in a region adjoining one where subsidence was continually taking place? Might not the

¹ Deprat, op. cit., Ire Partie, p. 69 et seq.

² *China*, vol. ii, p. 713.

general absence of Silurian and Devonian strata in the vast area of northern China be fitly interpreted as the result of a broad epeirogenic movement accompanying the slow Devonian transgression in the southern part of the country? The region on the south of the Tsing-ling belt apparently behaved as the fulcrum.

During the later part of the Devonian period China experienced little geographical and geological changes. Uniform subaerial denudation in the north progressed side by side with tranquil sedimentation in the south. In the meantime, the climatic conditions became suitable for exuberant growth of vegetation on the land; cosmopolitan types of organisms swarmed in the open ocean. With such a multitudinous development of plant and animal life the great coal-forming period was inaugurated in eastern Asia.

THE ANTHRACOLITHIC OR CARBONIFEROUS-PERMIAN.

The upper Palæozoic rocks are well developed in all parts of China, including the high mountain ranges of the Tsing-ling and the Nan-shan. The continuous and conformable nature of the formation that represents the transitional period from the Carboniferous to the Permian renders it difficult to select a definite plane for dividing the Carboniferous from the Permian as in the case of north-western Europe. The term "Anthracolithic", first introduced by Dr. W. Waagen, and recently adopted by Professor E. Haug for denoting the whole of the Carboniferous and Permian period, seems to be particularly suitable for Chinese geology.

Two facies of the Anthracolithic Formation are recognizable in China: the continental facies with thick seams of coal is principally distributed in the northern provinces, namely, Manchuria, Shan-tung, Chi-li, Shan-si, Ho-nan, Shen-si, and probably including the eastern part of Kan-su. This coal-bearing series is also known as the Shansian System. The marine facies with massive limestones is found in the southern provinces, namely, to the south of the Tsing-ling Range. In the lower Yang-tze Valley, the Tsing-ling Range, and the Nan-shan Ranges these two facies are more or less equally represented. The facies-character of the formation is, however, not absolutely confined to the several regions in such a way as outlined above. In the marine facies coal seams and other terrigenous deposits are not absent; while in the continental facies we find seams of true marine limestones which decrease in number and thickness towards the north. They entirely disappear in the Wan-ping coal-field, west of Peking, reappearing in the Kai-ping coal-field, eastern Chi-li, and Manchuria. Thanks to these intercalations, ere long we shall be able to attempt an accurate correlation of the Shansian strata.

Throughout northern China the Shansian formation generally rests at once on the Sinian limestone; the latter is sometimes erroneously called by miners the "Carboniferous Limestone" or the "Mountain Limestone". Richthofen, too, regarded the Sinian limestone in several parts of Shan-tung as the "Kohlenkalk". The upper

part of the Shansian System merges into a yellowish or reddish sandstone of considerable thickness, moderately coarse in texture and barren of fossils. This sandstone is often termed the "Plateau Sandstone" or the "Supracol Sandstone".

The Shansian System is divisible in the province of Shan-si into two series in the following descending order:—

- b. Productive Measures. Variegated sandstones with subordinate sandy shale containing anthracite seams of a thickness varying from 12 to 30 feet.
- a. Taiyang Series.¹ Alternating beds of limestones, ironstone-bearing shales, sandstones, and fire-clays with occasional seams of coal; capped in places by a highly fossiliferous black Fusulinidea limestone which often contains flints.

In the other provinces of northern China the general lithological character of the Shansian Formation is much the same. The Fusulinidea of the flinty limestone, as well as the ironstone-bearing beds, persist throughout a remarkably wide area. According to the *Record of the Work of the Geological Institute* this ferruginous stratum decreases in thickness from southern Shan-si towards the north, ranging from 37 mm. to a few metres. In western Shan-tung the Shansian System is locally known as the Poshan Series.² Apart from the intercalation, in the upper part of this series, of contemporaneous lava and tuff, there appears no notable lithological difference from its equivalent in Shan-si.

Several assemblages of marine fossils were found by Richthofen in the provinces of Shan-tung and Shan-si from the marine intercalations of the Shansian System. According to Professor Frech,³ the fauna which consists of *Productus semireticulatus*, *P. scabriculus*, *P. longispinus*, *P. giganteus*, *Spirifer duplicicosta*, *S. bisulcatus*, *S. (Martinia) glabra*, *Loxonema walciadolense*, *Macrocheilus* cf. *intermedius*, *Naticopsis* cf. *globulina*, etc., is as a whole comparable with that of the Viséian Limestone of Europe. That is to say, at least the lower part of the Shansian System belongs to the Lower Carboniferous. After an examination of several species of Brachiopods obtained from the limestone member of the Shansian System, Douville failed to arrive at any definite conclusion with respect to the age of their containing rock. He doubts whether the limestone is comparable with the black marble of Tonkin; the latter is generally considered as belonging to the Westphalian or possibly some earlier stage. Girty,⁴ after studying the marine fossils, including the species *Squamularia* cf. *perplexa*, *Chonetes* aff. *flemingi*, from Shan-tung and Shan-si, compares the Shansian System with the Pennsylvanian, viz. the Upper Carboniferous of North America; while Hayasaka⁵ endeavours to show that the marine fossiliferous zone of the Poshan Series is of the youngest Carboniferous age.

¹ *China*, vol. ii, pp. 406, 411.

² *Ibid.*, p. 203.

³ *Ibid.*, vol. v, pp. 63–76.

⁴ "Upper Palæozoic Fossils": *Proc. U.S. Nat. Hist. Mus.*, 1908, pp. 37–48.

⁵ *Journ. Geol. Soc. Tokyo*, vol. xxiv, No. 283, 1917, pp. 169–97.

(To be continued.)

REVIEWS.

DER BAU DER ERDE. By L. KOBER. pp. 324, with 2 plates, and 46 text-figures. Berlin: Gebrüder Borntraeger. 1921. Price 80 marks.

ALTHOUGH speculations on the plan of the earth, the distribution of land and sea, of mountain ranges, and other geographical features, are a subject of never-failing interest, most students of geology have come to the conclusion that life is not long enough to read Suess. *The Face of the Earth* is heavy going in any one of the three versions, the conclusions are not always clear, parts are out of date, and, owing to the long period that elapsed between the appearance of the first and last volumes the author's views had necessarily undergone important changes. In recent years many new facts have come to light and prevalent ideas have had to undergo revision. The book under review gives in small compass a summary of the present state of our knowledge on the structural features of the earth. It cannot be described as altogether an impartial statement, since the author is obviously arguing in favour of his own hypothesis. What that hypothesis is will be discussed later. The book is written in a clear and simple style, in short sentences very unlike the usual German manner, in fact, in places almost telegraphic, and occasionally the meaning of a sentence is rendered somewhat obscure by the absence of a principal verb.

The book begins with a discussion of the nature of the earth's crust, its thickness and composition, and its morphological subdivisions, emphasizing the contrast between the massive and permanent continental blocks and the folded regions, the latter originating as geosynclinals. For these last elements the word "Orogen" is employed, a word difficult to translate neatly, but perhaps best expressed as *orogenic zone*. Much importance is rightly attached to the different facies of sedimentation and the close connexion between types of earth movement and the Atlantic and Pacific igneous rock-families of Harker is strongly insisted on. The writer commits himself to the somewhat unusual view that the Atlantic (alkaline) magma is the typical world-magma of the depths, and that the Pacific magma is a special variety due to differentiation by orogenic movements. This is in absolute contradiction to the trend of modern opinion, especially in America.

The structures of continental masses and mountain chains are compared and contrasted, and the present plan of the surface is mainly attributed to Mesozoic geosynclinals. The account of the structure of the Alpine chains is specially clear, and brings out well the results of recent work in establishing the southward folding of the Eastern Alps and the Dinaric chains. The Alpine mountain system in general is interpreted as the boiling over of a geosynclinal between the jaws of a vice, as figured by Suess, but it is made clear that the

boiling over took place outwards in both directions. The Pyrenees, Alps, Carpathians, and Balkans, and perhaps the Caucasus form the northern limb, thrust northwards, while the Atlas, Apennines, Dinaric chains, Taurus and Iranian arc form the southern limb, thrust southwards. The connexion between the Atlas and Betic Cordillera at the Straits of Gibraltar is abandoned, and both chains are considered to run out into the Atlantic, towards the Azores and Antilles. Another unorthodox view is that the Appalachians are the direct continuation of the Caledonian chains of Norway and Scotland. For this little evidence is given, and we note here a tendency that prevails among nearly all writers on this subject, namely, to mix up mountain ranges of quite different ages, if only the directions coincide.

The general structure of all the principal mountain chains and of the continental blocks of the world is considered in more or less detail. It is impossible here to discuss the many interesting points raised. It must suffice to say that the author finally comes to the conclusion that the present plan of the earth consists of solid continental blocks, each surrounded by an orogenic ring; these blocks are eight in number, two of them being now submerged beneath the Pacific; the rest form the existing continents, Eurasia, Africa, Indo-Australia, North America, South America, and Antarctica. These continental blocks form an octahedron whose edges are the orogenic geosynclinals, and of which two of the corners are situated, one in the Azores, at the crossing of the Mediterranean geosynclinal and the central ridge of the Atlantic, which is regarded as another principal orogenic zone, and the other somewhere in the Sunda Archipelago. The point in the Azores is the apex of the land-pyramid, the other the apex of the water pyramid, or hemisphere, which together form the octahedron. All this is very nicely worked out, and then, finally, in the last two pages, the author seems strongly inclined to go back on himself and to pin his faith to the old tetrahedral theory of Lowthian Green.

With regard to the prime cause of earth-movements in general, and mountain building in particular, the theory of isostasy in its prevailing form is rejected, everything being referred to simple contraction of the earth, and attention is directed to the great diminution in the size of the earth, which must have accompanied the folding and compression of originally horizontal strata. It is calculated that the reduction of the earth's radius since the beginning of Palæozoic times must have amounted to several hundred miles.

Whatever opinion we may hold as to the value of the ideas set forth and the conclusions drawn, there can be no doubt that the book is very well written and will be of considerable value as a summary of the ideas now prevailing among continental geologists on this subject.

R. H. R.

THE STUDY OF GEOLOGICAL MAPS. By GERTRUDE L. ELLES, D.Sc.,
Fellow of Newnham College, Cambridge. pp. 74, with 7 plates
and 64 figures. Cambridge University Press. 12s. net.

GEOLOGISTS and teachers of geology in England will welcome this small book from the pen of so experienced a teacher and field worker as Miss Elles, and the more so since, as stated in the preface, it is based on lectures given by her for many years to honours students in geology, and has therefore been already put to the proof.

The first three chapters are given up to the exposition of topographical maps in their relation to geology, and full emphasis is given to the paramount importance of surface relief in the analysis of geological maps. One would perhaps expect this from an author whose work has been chiefly in the more rugged parts of these islands, but it is none the less commendable from the fact that such emphasis is frequently lacking in other works on geological maps.

The remainder of the book describes and illustrates methods of solving the problems of dip, thickness, relative age of strata, etc., from a geological map. The more complicated forms of outcrop given by folds, faults, overthrusts, and by igneous rocks are dealt with as fully as space permits. The great feature of the book is the frequent quotation of examples of the various types of formation to be found on the maps of the Geological Survey and the description of special areas on those maps. Full use is made of footnotes for reference to authorities or maps, so that the private student is introduced to the proper literature for fuller study.

In the solution of the problems recourse is had to the graphic methods of Harker, and these are illustrated with diagrams. The graphic constructions are dealt with in an appendix to the third chapter, and one is inclined to think that it is too condensed for the average reader who cannot have the benefit of personal demonstration. Experience leads one to believe that most students of geology find more difficulty in solving the problems of solid geometry that arise from geological maps than in anything else and a more detailed treatment would have added to the value of the book.

A final chapter on the interpretation of geological maps is excellent but all too brief, and tables of symbols and of the ordinary trigonometrical functions are added.

The book is very well illustrated with diagrams, sections, and maps, and a series of plates of block diagram drawings helps considerably in expounding the relation between surface relief and geological phenomena. After the excellence of the text-figures one is somewhat surprised to find the folding map at the end to be one of the less useful productions of the Ordnance Survey, exhibiting most prominently the two great faults of an irregular contour interval and heavy overprinting. The book is strongly bound and almost entirely free from printing errors, well up to the standard of the other books in the Cambridge Geological series. It is noteworthy,

however, that in order to accommodate the text-figures, the length of the lines has had to be increased, and it is not so easy to read as the other books.

To some extent the book may be regarded as complimentary to Harker's *Geological Map-reading*, and should therefore find many readers who require a less rigorous and theoretical treatment of the subject. The reviewer feels it necessary to point out, however, that in these two books on the study of geological maps we have but the latter half of the subject, the first half being the mapping in the field. To geologists in England, more or less adequately served by the maps of the Geological Survey, this may not appear to be of prime importance, but to anyone engaged in work in other countries, or in training people for such work, the need of an up-to-date text-book on geological field-mapping is very evident indeed. It is to be hoped that accomplished field workers such as the authors of these two books will consider that need and take steps to supply it.

F. D.

THE TIN RESOURCES OF THE BRITISH EMPIRE. By N. M. PENZER. pp. 358, with plates, maps, and charts (not numbered). London : W. Rider & Son, Ltd. 1921. Price 15s. net.

AS stated in a general introduction by Mr. J. S. M. Ward, this volume forms one of a series dealing with the raw materials of industry, and unlike the rest of the series it deals only with the British Empire ; the reason for this is that the amount of information available is very great, and it is hoped that a second volume on the tin supplies of other countries will appear at a later date. The author has evidently ransacked very thoroughly the literature of tin mining, which, as shown by the bibliography recently published by Mr. and Mrs. Hess, for the Smithsonian Institution, is of vast bulk. In the nature of things the accounts given of the different districts vary in scope and value, since our knowledge of some of them is complete and detailed while in other cases it is vague and scrappy. This is due to the different points of view of those who have attempted to describe them. The study of a book of this kind serves to bring out very strongly the urgent need for a more systematic scientific training for mining engineers, or perhaps, to express it better, the need for a class of scientific mining geologists to supplement the work of the engineer. Only when this is brought about shall we attain to consistent and scientific descriptions of the mineral deposits of the world, especially of its more remote regions. The author has made good use of the material available, and has succeeded in giving an interesting and readable account of his subject, supplemented by many statistics, with maps and plans, and a bibliography of some forty-five pages, arranged topographically, is a valuable addition to the book.

THE WEST RIDING OF YORKSHIRE. By BERNARD HOBSON, M.Sc., F.G.S., xii + 188 pp., with 48 illustrations (not numbered), 7 diagrams, and 2 coloured maps. Cambridge University Press. 1921.

THIS, the latest addition to the well-known series of Cambridge County Handbooks, maintains the standard of its predecessors, and comprises a useful description of the natural and artificial features of the area under review. In the West Riding of Yorkshire the study of geology is of supreme importance from the commercial point of view, and the Coal Measures still present many unsolved problems of a technical character. On the theoretical side there are still questions of absorbing interest, as shown, for example, in a recent illuminating address by Professor Marr. The exact age of the oldest rocks of all, the Ingletonian series, is still unsettled, but there can be no possible doubt from their structures, lithological characters, and degree of alteration, that they are of very early date. These, together with the Lower Palæozoic rocks, have evidently been crushed up against a still more ancient mass, as so clearly shown by Professor Marr, and it is the nature of this ancient horst under the northern Pennines that provides such an interesting subject for speculation by theoretical geologists. Another still unsolved problem of a cognate character is the reason for the great change in thickness of the Lower Carboniferous at or near the Craven faults; this also is undoubtedly tectonic in its origin, and is a striking example of an abrupt change of facies. Space, however, will not permit of a further discussion of the features of the underground or superficial geology of this area. In this book the author gives a clear account of the topography of the Riding, and its dependence on geological structure, and his account of the special characteristics of the limestone regions will be tantalizing to those not personally acquainted with them.

With regard to the coloured geological map here provided, we can only say that it is simply deplorable, being thoroughly badly produced, and full of the most glaring errors. We cannot understand how the Cambridge University Press could allow such a thing to be issued under its auspices.

ORE DEPOSITION IN THE BOLIVIAN TIN-SILVER DEPOSITS. By W. MYRON DAVY. *Economic Geology*, vol. xv, 1920. pp. 463-96, with 2 plates and 4 text-figures.

THE author discusses previous work on the tin-silver deposits of the Cordillera Real and its south-eastern extension to Potosí. He shows that the whole of the tin mineralization was approximately contemporaneous and that the lodes can be divided into three types: (a) tin-tourmaline lodes of the high temperature zone, without silver; (b) tin-silver lodes of the intermediate zones; (c) silver lodes without tin. Each type is correlated with and due to igneous activity,

type (a) being in and near deep-seated Tertiary granites, type (b) associated with intrusive porphyries, and (c) with extrusive lava-flows. A notable feature in type (b) is the abundance of stannite, which by oxidation has given rise to large deposits of wood-tin. Bismuth minerals are also abundant, but the author does not mention wolfram, which has of late been largely mined in this area. A brief reference is made to the occurrence of argyrodite and other germanium minerals. The origin of the ores by differentiation of igneous magmas is discussed, and the unusual association of tin and silver is attributed to incomplete differentiation before eruption. The author considers that the ore-deposits of this area offer a favourable field for future development, though mining is hindered by the great height of the country and the consequent severity of the climate.

R. H. R.

LATERIT IN WEST-AUSTRALIEN. By J. WALTHER. *Zeits. d. Deuts. Geol. Ges.* Vol. lxvii, 1915, pp. 113-32, with 2 plates and 1 text-figure.

A CAREFUL examination of the laterite region of West Australia in 1915 and a comparison of it with many other regions have led the author to some general conclusions. In this paper he expresses his definite opinion that laterization is not a phenomenon characteristic of the present climate of moist tropical regions, as stated or implied by many writers. Professor Walther considers that laterization went on during a past climatic phase, when there was a very well-marked alternation of annual extremes of drought and rainfall. This he supposes to have occurred in the "diluvial period", whatever that may mean. As a matter of fact, this conclusion, as to the necessity for strongly accentuated wet and dry seasons for laterization, was reached many years ago by Indian geologists.

This paper gives a graphic account of the peculiar topography and dry "lakes" of the more arid parts of Western Australia, and should be of service to all those interested in the subject.

A GEOLOGICAL EXCURSION HANDBOOK FOR THE BRISTOL DISTRICT. By S. H. REYNOLDS, Sc.D., F.G.S., Second edition. pp. 224, with 50 figures. Bristol: J. W. Arrowsmith, Ltd. Price 5s. net.

WE observe with pleasure that it has become necessary to issue a second edition of this admirable handbook, first published in 1912. In view of much recent work on the geology of the Bristol district, a large number of small additions to and corrections of the text have been made, and five new illustrations are included. It is impossible to exaggerate the usefulness of books of this kind, written by competent authorities, and in this case the name of the author is a sufficient guarantee of adequate treatment. The Bristol district

is an area of exceptional interest to the geologist, who, with this book in hand, should be able to find his way to all the important sections and exposures, and what is usually difficult without personal guidance, to understand them when he gets there.

METEOROLOGY. By A. E. M. GEDDES. pp. xx + 390, with 20 plates, some coloured, 11 charts, and 103 figures. London: Blackie and Son, Ltd. 1921.

IT is scarcely necessary to remind geologists of the important part played in their science by the mass of phenomena generally summed up in the word climate. In fact, this is in some ways one of the most important factors in geology. We, therefore, welcome the appearance of this book, which gives in a clear form the results of the latest investigations in meteorology and the physics of the atmosphere in a form convenient for reference. This subject has made great strides of late years owing to the possibility of observations at great heights, and some of our earlier ideas have had to be modified. It is more with climate and meteorological phenomena as seen near the surface that the geologist is directly concerned, nevertheless, the circulation of the upper atmosphere and its control of temperature and rainfall are also of great importance.

Some of the plates, reproductions of cloud-photographs, are very beautiful.

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SEPTEMBER, 1921.

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THE GEOLOGICAL MAGAZINE

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Founders of Seismology.—III. John Milne.

By CHARLES DAVISON, Sc.D.

DURING the period of about ten years which included that of Mallet's death—say, five years before and five after—the study of earthquakes made rapid progress. Among the more prominent contributors were M. S. de Rossi and G. Mercalli in Italy, F. A. Forel and A. Heim in Switzerland, E. Suess in Austria, J. F. J. Schmidt in Greece, T. Oldham in India, and C. G. Rockwood and C. E. Dutton in the United States. Their work, however, was mainly carried out on the old lines. For the introduction of new methods of study and of a new spirit infused into seismology, we are indebted to the small band of early British teachers in Japan, to J. A. Ewing, T. Gray, and, above all, to J. Milne. In the new epoch, now opening, when seismology demanded the whole energy of its supporters as well as their active co-operation, it is not, I think, too much to claim that Milne lifted the science to an altogether different and higher plane.

To readers of the GEOLOGICAL MAGAZINE, the details of Milne's life are well known, and may here be passed over rapidly. He was born at Liverpool on 30th December, 1850, and received his training as a mining engineer under Warrington Smyth at what was then the Royal School of Mines. After a few years of travelling (in Newfoundland, Labrador, and Arabia), he was appointed in 1875 to the professorship of geology and mining in the Imperial College of the Public Works Department at Tokyo. Travelling overland, he reached Japan early in 1876, his first night in Tokyo giving him an introduction to Japanese earthquakes.

For the next four years the direction of Milne's study was undecided. Then, on 22nd February, 1880, there came the strong earthquake which wrought so much havoc in Yokohama, and from this time onward his attention hardly wavered from seismology. On his initiative a public meeting was called, which resulted in the foundation of the Seismological Society of Japan, with J. Hattori as president, and himself as vice-president and secretary. For twelve years the Society flourished, coming to an end in 1892, when its work was continued and extended by the Imperial Earthquake Investigation Committee. The *Transactions* of the Society, of which sixteen volumes were published, then merged into the *Seismological Journal of Japan*, four volumes being issued from 1893 to 1895. In the latter year Milne left Japan, the close of his residence being

unfortunately marked by the burning of his library and seismological observatory. He reached England in July, and, with his Japanese wife, made his home at Shide Hill House, near Newport, in the Isle of Wight.

From 1880 onwards Milne's work was aided by grants from the British Association. The reports which he wrote as secretary of the Committee on the Earthquake Phenomena of Japan contain useful summaries of the work which he carried out in that country. At the first meeting of the Association (1895) after his arrival in England this committee and the Earth Tremors Committee were merged into the Seismological Committee, Milne continuing to act as secretary until his death, after a short illness, on 31st July, 1913.

Though Milne contributed most of his work to scientific journals, he wrote two well-known volumes on *Earthquakes* (1886) and *Seismology* (1898) for the "International Scientific Series". Of the twenty volumes of *Transactions* and *Journal* published in Japan, he was the author of not less than two-thirds. He wrote fifteen reports of the Committee on the Earthquake Phenomena of Japan, and the greater part of eighteen reports of the Seismological Committee,¹ in addition to many other papers in various journals.

Milne differed from Michell and Mallet in his preference for co-operating with others. He was not a solitary student. Retaining to the last the cheerfulness of youth, gifted with an abiding sense of humour, kindly and hospitable, possessing not only enthusiasm but also the power of kindling in others the same eagerness, abounding in energy and loving hard work, Milne was admirably adapted—no man better—to act as a founder of the now widening science of seismology.²

The chief difficulty in summarizing Milne's work is its wide extent and range. Michell wrote but one memoir. Mallet's work, though it covered about sixteen years of an active life, was described in less than twenty papers and one book. Milne penetrated into nearly every corner of seismology, and his papers, if collected, would fill many volumes. I will endeavour to group his work under various headings, but to do this within a limited space minor details must be omitted, and a strictly chronological order to some extent abandoned.

Investigation of Earthquakes.—Milne was a student of earthquake phenomena rather than of earthquakes, and the strong shock of 1880 is the only one that he can be said to have investigated. At this early date the disadvantages under which he worked were great. The Japanese public were not then educated in the observation of earthquakes. De Rossi's first scale of seismic intensity was devised in 1874, but it was probably unknown outside Italy. Milne had therefore to depend on observations of the time and direction of the

¹ In the following pages these will be referred to as *Trans.*, *Journ.*, and *Rep.*, respectively.

² For the above biographical details I am indebted chiefly to articles in the *GEOL. MAG.*, 1912, pp. 337–46 (with portraits), *Proc. Roy. Soc.*, vol. 89, 1914, pp. xxii–xxv; *Bull. Seis. Soc. America*, vol. 2, 1912, pp. 2–7.

shock, the latter alone being found to possess any value. These enabled him to fix the position and form of the epicentral area. To determine the depth of the focus he measured seven angles of emergence at Tokyo and Yokohama from the horizontal and vertical motions given by various instruments, and concluded that the most probable of the resulting depths are from $1\frac{1}{2}$ to 5 miles. Two other subjects on which Milne collected many observations were also considered—the rotation of chimneys and gravestones and the nature of the damage to buildings. In the Yokohama cemetery, for instance, the gravestones are arranged in parallel rows, and the stones were rotated in one direction only. This uniformity of rotation is clearly inconsistent with the explanation given by Mallet, and Milne preferred one suggested to him by his colleague T. Gray. The other subject, then and afterwards, was constantly before Milne's mind, and in this paper we see his first attempt to provide rules for the construction of earthquake-proof buildings.

Under this heading may also be included the paper on the Peruvian earthquake of 9th May, 1877, though it refers mostly to the sea-waves which were propagated across the Pacific to the coasts of Japan. The position of the epicentre was ascertained from observations on the time of occurrence, and one of the chief conclusions of the paper is that the mean depths, calculated from the measured velocities by means of the formula $v = \sqrt{gh}$, are less than those obtained from soundings. Milne suggests that the figures obtained from soundings may be excessive, but it was afterwards shown that the inequality observed must result from variations in the depth of the ocean.¹

Construction of Seismographs.—Looking back after an interval of thirty or forty years it would seem that the chief debt that we owe to the Seismological Society of Japan is the construction of accurately recording seismographs. In the designing of these instruments the larger share fell to J. A. Ewing and T. Gray, the former being responsible for the invention of the horizontal motion seismograph (1880) and the duplex pendulum seismograph (1882), and the latter for that of the vertical motion seismograph (1881). To Milne we are indebted for the testing of the various instruments and for many improvements in detail. Probably no other seismologist has had so wide an experience as Milne of the seismograph in all its different forms. He wisely began with the simple apparatus in use at Comrie forty years before, and with those recommended, but not tested, by Mallet in the "Admiralty Manual"; but common pendulums, vessels filled with liquids, bodies floating in water, columns cylindrical and otherwise, and vertical springs were all, for one reason or another, found wanting. For several years (1872–85), the Tokyo earthquake record was made by a Palmieri seismograph. In the latter year this instrument was replaced by a Gray-Milne seismograph,

¹ *Trans.*, vol. 1, pt. 2, 1880, pp. 1–116; vol. 2, 1880, pp. 50–96; see also *Phil. Mag.*, vol. 43, 1897, pp. 33–6.

a combination of horizontal motion pendulums of the Ewing type and a Gray vertical motion seismograph, all recording in ink on a continuously moving strip of paper, so that the register could be continued without interruption except for the brief interval during which the paper was being changed.

In 1880 Gray had rediscovered the type of horizontal pendulum first devised by A. Gerard in 1851, the heavy mass being carried on a horizontal rod, the pointed end of which rests in a conical hole of the upright frame, while the mass is supported by a wire attached to a point of the frame nearly but not quite vertically above the pointed end of the rod. Realizing the value of such a pendulum for the registration of distant earthquakes, Milne, before he left Japan (1892), invented the instrument afterwards widely known as the Milne seismograph. With various modifications, it became for many years the standard instrument of the Seismological Committee of the British Association, and with it a vast amount of useful work was done. It is now being gradually replaced by the much-improved Milne-Shaw seismograph.

Nature of Earthquake-Motion.—One can well understand the interest of the early meetings of the Seismological Society when the first precise records of earthquake-motion were exhibited by Ewing and Milne. Most of the shocks in those days were comparatively slight, but they were strong enough to reveal the general character of the motion. Some of the results were unexpected, especially the small amplitude of the movement, which, in ordinary earthquakes is often less than one millimetre and seldom exceeds a few millimetres, while the maximum acceleration usually ranges from 10 to 100 mm. per second per second, and only in destructive earthquakes surpasses 500 mm. per second per second. The main conclusions are perhaps too well known to require rehearsal here. Some reference must, however, be made to the many seismic experiments which Milne conducted, for the most part in conjunction with Gray, and to Milne's study of the variations of the movement within a small area and under certain artificial conditions.

The registration of earthquakes, it might at first sight be expected, would give all the information desired. But the earthquakes came at uncertain times and from different regions. The observing stations were limited in number and required arrangement with reference to the source of disturbance. Above all, that source was usually of considerable size, and distortional vibrations from the nearer parts of the focus combined with condensational vibrations from more distant portions. It was necessary, therefore, to simplify the disturbance, and this was attained by explosions of dynamite and by dropping a heavy weight (1710 lb.) from various heights up to 35 feet.

The most interesting result of the experiments was the complete separation of the condensational and distortional vibrations. When the record was made with a single index on a fixed glass plate, the

index first moved in a straight line away from the origin. After this it was suddenly deflected and yielded a diagram in which the movement was elliptical or in the form of the figure 8, the two sets of vibrations being then compounded. When, however, two bracket seismographs of the Ewing type were installed, one to record the movement in the direction of the source, and the other in the perpendicular direction, the vibrations of the two types were kept apart, and the variations of each could be studied. Near the origin the amplitude of the condensational vibration was the greater, but died out more rapidly than that of the others with increasing distance from the origin. In both types of vibration the period increased as the waves diverged. In the velocity of the waves Milne found many variations. It increased, for instance, with the strength of the disturbance, and, in any one artificial earthquake, it diminished as the waves spread outwards. In the condensational vibrations the mean velocity was 438 feet per second; in the distortional vibrations, 357 feet per second. The effect of inequalities in the ground were also studied. Small hills seemed to interpose but little obstacle to the waves; excavations, such as ponds, checked the passage of both types of vibration.

A matter of some practical consequence brought out by these experiments is that two points of ground only a few feet apart did not always synchronize in their movements. This result led Milne to make some further observations during earthquakes, and he was able to show that points only 3 or 4 feet apart experienced slightly different motions. He also made a seismic survey of about 9 acres in the grounds of the Imperial College of Engineering at Tokyo. On the west side the ground is somewhat marshy; elsewhere it is dry and hard. He found that, as is now well known, the maximum acceleration (which measures the intensity of the shock) was greater on the soft than on the hard ground. An unexpected result was that the acceleration at the bottom of a pit 10 feet deep was much less than at the surface.¹

Catalogues of Japanese Earthquakes.—During his residence abroad Milne compiled two catalogues of Japanese earthquakes, one showing the distribution of seismic activity in past time, the other the distribution throughout the country within a limited period. The earlier catalogue is less well known than it deserves. It contains a list of 366 great earthquakes, from 295 B.C. to A.D. 1872, and gives for each shock the date, the intensity (according to a rough scale of two degrees), and the district chiefly affected. One result obtained from this catalogue is worth noticing. The increase in the number of entries towards the present day, which is so characteristic a feature of all other catalogues extending over many centuries, is not observable here from the seventh century onwards. The probable explanation, according to Milne, is that Japan has remained through-

¹ *Trans.*, vol. 10, 1887, pp. 1-36; vol. 12, 1888, pp. 63-6, 67-75; vol. 13, 1890, pp. 41-89.

out in the same state of civilization, while other countries have emerged from a state of semi-barbarism.¹

Soon after the foundation of the Seismological Society, Milne began the systematic study of the distribution of Japanese earthquakes. He adopted the plan of distributing bundles of postcards among the Government offices in all important towns within a hundred miles of Tokyo. Every week a postcard was to be returned to him with notes of any earthquakes observed. The results of two years (1881–3) were enough to show the efficiency of the method (387 earthquakes were recorded during this time in north Japan), and to reveal the principal laws of distribution. The “barricade of postcards” was then extended northwards as far as Sapporo, 450 miles from Tokyo, but the labour and expense were becoming too great to be borne by one man, and the Imperial Meteorological Department, with its 968 reporting stations, was induced to carry on the work. The materials for the eight years 1885–92 were afterwards placed in Milne’s hands, and thus enabled him to prepare his great catalogue of 8,331 earthquakes recorded in Japan during these years.

The value of this catalogue and the immense labour involved in its preparation can only be appreciated by those who, like myself, have spent some time in analysing its contents. For convenience of printing, the catalogue is in two parts. Together they give, for every earthquake, the date, the extent of the area disturbed, and the lengths of its axes, the position of the epicentre, and, when submarine, its distance from the nearest coast.²

Distribution of Japanese Earthquakes.—It was characteristic of Milne that he left the discussion of his great catalogue for the most part to other workers. He was mainly interested himself in studying the distribution of the Japanese earthquakes in space. For this purpose he divided the map of the whole country into more than two thousand rectangles by north-south and east-west lines one-sixth of a degree of longitude and latitude apart. These rectangles are all numbered, and the position of the epicentre in the catalogue is indicated by the number of the rectangle in which it lies. On the map, the epicentres are represented by dots spread uniformly over each rectangle, and it is seen at once that these dots are grouped in fifteen districts with definite boundaries, except that, in two districts, the shocks were so numerous that the boundaries are represented as straight lines beyond the proper limits, as there would not otherwise have been room to insert the dots.³

¹ Milne’s catalogue of great Japanese earthquakes has been superseded by “The Earthquake Investigation Committee Catalogue of Japanese Earthquakes”, compiled under the superintendence of the late S. Sekiya (*Journ. Coll. Sci., Imp. Univ., Tokyo*, vol. 11, 1899, pp. 315–88, with a discussion by F. Omori, pp. 389–437).

² *Trans.*, vol. 3, 1881, pp. 65–102; vol. 4, 1882, pp. 1–30; vol. 7, pt. 2, 1884, pp. 1–87; *Journ.*, vol. 4, 1895, pp. i–xxi, 1–367.

³ Another method of representing the distribution of these earthquakes is illustrated in the *Geogr. Journ.*, vol. 10, 1897, pp. 530–35.

The map confirms in detail the laws of distribution which Milne had already deduced from the earthquakes of north Japan during the years 1881-3. Of those earthquakes 84 per cent originated near the sea-coast or beneath the ocean. He again notices that the majority of earthquakes originate along the east coast and that in many of them the epicentres are submarine. Drawing lines in an east and south-east direction from the highlands of Japan into the Pacific Ocean, he found that the slope in places is as much as one in thirty or twenty, and that it was in such districts where the surface-flexures are greatest that the earthquakes are most frequent and violent. A second and somewhat unexpected result is that the central portion of Japan, in which active volcanoes are numerous, is singularly free from earthquakes. Lastly, Milne showed that with two or three exceptions the districts in which earthquakes are frequent are also those in which movements of secular elevation and depression are taking place.¹

Catalogue of Destructive Earthquakes.—The homogeneity of the second catalogue of Japanese earthquakes fails us in all catalogues extending over many centuries. Milne sought to restore this valuable feature to his last great work—the catalogue of destructive earthquakes—by confining it to shocks which have caused some marked injury to property, those due to “movements which have probably resulted in the creation or extension of a line of fault”. Even so, the catalogue is inevitably incomplete. For instance, during the first thousand years of the Christian era the records of three out of every four earthquakes come from Italy, China, and Japan; during the nineteenth century the proportion drops to one in five. Many of our seismic records only began to exist during the last five centuries, that of America in 1520, of the Philippine Islands in 1600, of India in 1668, and of New Zealand in 1848. Nevertheless, unless some unexpected sources of information should be disclosed, it seems unlikely that very material additions can be made to Milne’s catalogue. It must be regarded as exhaustive as it is now possible to render it.

The catalogue, which occupied Milne for several years, was published in 1911. It covers a period of 1893 years, from A.D. 7 to 1899, and contains 4,151 entries. As far as possible it states for every earthquake the year, month, and day of its occurrence; the country visited by it, and often the part of the country in which it was felt most strongly; the intensity of the shock according to a scale of three degrees; and lastly the authorities for the information given. Sometimes a few details are added, such as the number of lives lost or of houses destroyed, which furnish a more precise idea of the disastrous character of the earthquake.²

Distribution of Earthquakes in Time.—Incomplete as the catalogue may be for the whole world, Milne points out that for Europe from

¹ *Journ.*, vol. 4, 1895, pp. xiv-xvii.

² *Rep. Brit. Assoc.*, 1911, pp. 649-740.

the year 1000 the most destructive of all earthquakes can hardly have escaped record. They were events of historical importance. Grouping them in periods of fifty years, from A.D. 1000 to 1850, he shows that, from about the year 1650 there has been a rapid increase in frequency, the numbers in successive half-centuries from 1600 being 3, 10, 15, 17, and 30. He suggests that these figures indicate a real increase in seismic activity from about 1650, accompanied, as he showed later, by a corresponding increase in volcanic activity.

The rest of Milne's work on the variations of earthquake-frequency must be noticed somewhat slightly, as, owing to the brevity of his record of world-shaking earthquakes, the results must be regarded as suggestive rather than as established. Like Mallet, he was attracted by the alternations of seismic activity and repose, and he showed that earthquakes have a tendency to occur in groups, the number in a group usually varying from two to fifteen or more, the groups lasting from one to three days, seldom more than six days. The interval between the centres of successive groups varies from fifteen to fifty days, being roughly proportional to the intensity of the earlier group.

More remarkable still is the tendency of strong earthquakes to occur in pairs, and even in triplets, in districts so widely separated as, for instance, Guatemala and the Indian Ocean (19th April, 1902), the interval between them being in this case less than the time required for the first preliminary tremors to cross the distance between the foci. Milne records fifteen cases of great double earthquakes, and two of triple earthquakes, during the years 1899–1906.

Such inquiries lead naturally to the suggestion that the variations of frequency in widely separated districts may to a certain extent be synchronous. The materials are perhaps at present insufficient for such wide generalizations, but Milne gives reasons for supposing that, in two districts so far apart as the eastern and western margins of the Pacific, the frequency in one increases and decreases simultaneously with that in the other; and that during the last two centuries, Italy, Japan, China, and America have roughly agreed in their periods of activity and repose.

The last point to which I can refer is Milne's interesting suggestion that the frequency of great earthquakes may be connected with the migrations of the pole. The earthquakes of the years 1892–1904 were grouped in successive intervals of $36\frac{1}{2}$ days each. Counting the earthquakes in those intervals in which changes of direction took place in the movements of the pole, and in the preceding and following intervals, Milne found the numbers to be respectively 287, 167, and 217, and he thus concludes that great earthquakes are frequent about the times when changes occur in the direction of the polar movements, and especially when those changes occur most rapidly.¹

¹ *Rep.*, 1900, pp. 107–108; 1903, pp. 78–80; 1906, pp. 97–9; 1908, pp. 78–9; 1909, pp. 56–8; 1910, pp. 54–5; 1911, pp. 32–5, 36–8; 1912, pp. 92–4.

The Study of Distant Earthquakes.—Milne's study of earthquakes extended over an interval of about thirty-three years. From 1880 to 1892, or during the existence of the Seismological Society, he was mainly concerned with ordinary earthquakes as they are felt within their disturbed areas. The next three years, while he was editing the *Seismological Journal*, formed a period of transition; his attention was divided between local and distant earthquakes; he was experimenting with the horizontal pendulum, afterwards known as the Milne seismograph. From 1895 until his death in 1913, or during his second residence in England, his time was chiefly devoted to the observation of distant earthquakes, with occasional digressions on the distribution of great earthquakes in space and time. In the present section I will touch briefly—for his work is so recent and well known—on his contributions to the latest and most fascinating development of seismology.

As far back as 1883, Milne had foreseen this development when he wrote that "it is not unlikely that every large earthquake might, with proper instrumental appliances, be recorded at any point on the land-surface of our globe". But it was not until 1889 that his attention was thoroughly aroused. In that year many Japanese and other earthquakes were recorded by von Rebeur-Paschwitz's horizontal pendulum at Potsdam, Wilhelmshaven, and elsewhere. Four years later Milne was observing distant earthquakes in Tokyo with his own seismograph, and his last report (1895) on the earthquake phenomena of Japan contains a list of some of the shocks recorded there before his observatory was destroyed. He reached Shide on 30th July, 1895, and within three weeks a brick pier was built, and the first horizontal pendulum erected in what afterwards became the central earthquake-observatory in the world.

In 1894 von Rebeur-Paschwitz suggested the foundation of an international system of earthquake-observatories, but his early death within the next twelve months cut short a promising career and delayed for several years the fulfilment of his plan. Shortly afterwards Milne independently conceived a similar and much wider network of stations, and in 1897 the Seismological Committee adopted his horizontal pendulum as the standard instrument for the purpose. Beginning with his observatory at Shide, the network of stations extended year by year, until the number of stations contributing records to the committee amounted to thirty-four. In the British possessions they were to be found in Canada and British Columbia, in Ascension and the Cape of Good Hope, and in various districts of India, Australia, and New Zealand. Records were also sent to the Committee from several observatories in foreign countries—from Spain, the Azores, and Syria, and from such distant island stations as Fernando Noronha and Honolulu.

The reports of the Seismological Committee, so far as Milne was responsible for them, are chiefly concerned with the discussion of the registers from these various stations. He touched, however,

on many subjects, some of which—such as earth-tremors, the diurnal wave, and the tilting due to tidal loading—have no apparent connexion with earthquakes. The sections on the distribution of earthquakes in time have been already noticed. Some others relating to distant earthquakes—such as earthquake-echoes, the nature of the large waves, and the dissipation of earthquake-motion as the waves radiate outwards—must here be passed over. In the remaining outline of Milne's work I will confine myself to two important subjects—the time-curves of the different phases and the distribution of the earthquake-origins in space.

It is interesting to trace Milne's successive attempts to draw the average time-curves of the earthquake-motion. The first, which is really a velocity-curve, appeared in the report for 1897, but the observations (for earthquakes of 1891-6) were discordant, and the only result deduced was an increase in the velocity of the early tremors with the distance, whether measured along the arc or the chord. In the following year an advance was made by separating the preliminary tremors and the large waves, and a curve was given showing very clearly that the average duration of the preliminary tremors increased with the arcual distance of the origin. In 1900—these years are dates in the history of seismology—the first time-curves proper were drawn. Distances from the epicentre in degrees of arc were measured along the horizontal axis, and the times of transit of the initial preliminary tremors and the maxima of the large waves to particular stations in the perpendicular direction. The time-curve for the large waves is practically a straight line, corresponding to a constant arcual velocity of 3 kms. per second; that for the preliminary tremors shows that the velocity along the arc increases with the distance. Two years later the curves begin to assume their now familiar form; and, as they are based on records from Milne's seismographs only, the divergences from the average are less noticeable than before. It had been shown by Oldham in 1900 that the preliminary tremors are divisible into two series, the first consisting mainly of condensational, the second of distortional, vibrations. A curve of the duration of the first preliminary tremors was also added. In the 1903 report the bearing of these curves is discussed. Measured along the arc from 20° to 150° from the origin, the velocity of the first tremors increases from 10·5 to 16·3 kms. per second. Measured along the chord the velocity is more nearly uniform, increasing from 10·5 to 12·0 kms. per second, and showing that there is apparently a slight increase in speed as the paths approach the centre of the earth. The interpretation which these observations require according to Milne is a "globe with an approximately uniform nucleus not less than $\frac{1}{20}$ of the earth's radius covered by a shell which passes rapidly upwards into the materials which constitute the crust of the world".¹

¹ Since 1902, many hundreds of new observations have been collected, and these have naturally modified Milne's curves and the tables founded on them.

To locate the epicentre of a distant earthquake Milne employed chiefly two methods. The first depended on the constancy of the velocity of the maximum large waves and required the absolute times of their passage at not less than four stations. The second depended on the fact that the interval between the initial tremors and the maximum large waves is constant for the same distance from the epicentre and varies with the distance. Thus, if the interval were given for at least three stations, the corresponding distance could be determined from the time-curves and tables, and the intersection of the circles with centres at the stations and these distances as radii would give the position of the epicentre.

In the report for 1900 the first map of earthquake-origins (for 1899) was given, the positions of the epicentres being denoted by small circles. By 1902, the number of origins being increased, Milne found it possible to define the principal regions of seismic activity. From this time onwards the map was a feature of each year's report, retaining the same form until 1910, when greater detail could be attempted. The great merit of the maps is their completeness, for of the stronger shocks not one can now escape being recorded. On the other hand, the period that has elapsed since 1899 is but a brief interval in the history of the earth, and all that the maps can provide us with is an outline of those districts in which crustal changes are at the present time taking place most rapidly. From the map for 1899-1909 we see that of every ten earthquakes seven belong to the districts bordering the Pacific Ocean, one to the strictly oceanic districts of the Indian and Atlantic Oceans, and two to the great terrestrial district which extends from the Apennines to the east of the Himalayas.

Conclusion.—In the preceding summary of Milne's work in seismology, I have omitted many points of interest. As somewhat outside our range I have left untouched the practical applications to which he humanely devoted so much of his time and attention, and especially to the structure of earthquake-proof buildings.¹ In common with other seismologists, Milne became absorbed for a time (especially 1884-6) in the study of earth-tremors. The early results obtained with his "automatic tremor recorder" were to some extent corrected by his later observations with the horizontal pendulum. Moreover, the connexion between earthquakes and tremors seems to be somewhat remote.² In 1897 he read an

The latest and most trustworthy tables are those prepared by Turner and published in the Circulars issued by the Seismological Committee. The bearing of the time-curves and especially that of the second preliminary tremors, on the constitution of the earth, has been discussed by several writers, especially R. D. Oldham (*Quart. Journ. Geol. Soc.*, vol. 62, 1906, pp. 456-73) and C. G. Knott (*Proc. Roy. Soc. Edin.*, vol. 39, 1919, pp. 157-208).

¹ *Trans.*, vol. 1, pt. 2, 1880, pp. 64-85; vol. 2, 1880, pp. 27-38; vol. 11, 1887, pp. 115-74; vol. 14, 1889, pp. 1-246; vol. 15, 1890, pp. 163-9.

² *Trans.*, vol. 7, pt. 1, 1883-4, pp. 1-15; vol. 11, 1887, pp. 1-78; vol. 13, 1890, pp. 7-20; *Rep.*, 1895, pp. 27-31.

interesting paper before the Royal Geographical Society on sub-oceanic changes as revealed by the fracture of telegraph-cables.¹ There were, indeed, few branches of seismology to which at one time or another Milne did not attend. On only one important subject did he touch less than might have been expected, namely, the origin of earthquakes, but the references which he made to it here and there show that he held the modern view which attributes earthquakes to the formation and growth of faults.

To state, as I have done for Michell and Mallet, what seem to me to be the contributions of permanent value which Milne made to seismology would be merely to abbreviate and repeat the preceding pages. I will therefore confine these concluding remarks to two general features.

In a history of seismology, Milne's work must for all time occupy a large and worthy place. In our textbooks of the future, in books which aim at presenting a summary of the then existing knowledge, the references may be fewer as time goes on than his work deserves. It must be remembered that Milne was a student of earthquake-phenomena, and that our knowledge of the phenomena is always growing. A careful investigation of a great earthquake, on the other hand, retains its value, for it cannot be replaced. Moreover, he preferred sometimes to start an inquiry and to leave others to finish it, to open up large views and to provide promising subjects of inquiry for a future of wider knowledge. Of his two great catalogues—of Japanese earthquakes and destructive earthquakes—his own analysis was slight. He was, in fact, content to provide the materials which others were to use in building.

The influence of a leader in science extends far beyond his own contributions. In founding the Seismological Society of Japan, which led to the formation of the Imperial Earthquake Investigation Committee, and in organizing the network of stations throughout the world, and, above all, in his personal influence on those with whom he came in touch, it seems to me possible that seismology may owe almost as much to his guidance and inspiration as it does to the incessant labour of his well-spent life.

¹ *Geogr. Journ.*, vol. 10, 1897, pp. 129-46, 259-85.

ORIGINAL ARTICLES.

The Use of Graphs in Palaeontology

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University College, Nottingham.

(Concluded from p. 364.)

EXAMPLES FROM CARBONIFEROUS CORALS.

To illustrate the value of graphic methods when changes in a number of distinct structural elements are studied, examples may be taken from the Carboniferous corals. These are well suited to the purpose, because thin slices yield so much information and are easily measured. In Fig. 4 a diagrammatic section is shown of one of the most highly organized corals, which exhibits the following important structural units: epitheca, tabulæ, septa, dissepiments, tabellæ, lamellæ, columella.

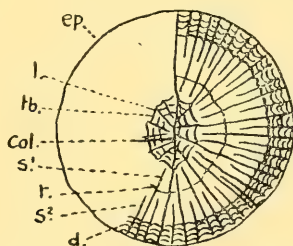


FIG. 4.—Diagrammatic section of *Dibunophyllum* showing the structural elements with which it is constructed. *ep.* epitheca, *l.* lamella, *tb.* tabella, *col.* columella, *s¹.* major septum, *t.* tabula, *s².* minor septum, *d.* dissepiment.

As shown by the accompanying table (Table I), the mere presence, or absence, of one or more of these units constitutes an important diagnostic feature for many genera. This table shows that these

	Tabulæ.	Septa.	Dissepiments.	Tabellæ.	Lamellæ.	Columellæ.
<i>Favosites.</i>	×	—	—	—	—	—
<i>Zaphrentis.</i>	×	×	—	—	—	—
<i>Caninia.</i>	×	×	×	—	—	—
<i>Cyathophyllum.</i>	×	×	×	×	—	—
<i>Aulophyllum.</i>	×	×	×	×	×	—
<i>Dibunophyllum.</i>	×	×	×	×	×	×
<i>Lithostroton.</i>	×	×	×	—	—	×
<i>Cystiphyllum.</i>	×	—	×	—	—	—
<i>Duncanella.</i>	—	×	—	—	—	—

TABLE I.—This illustrates the combinations of structural elements present in various corals. × element present, — element absent.

units are not so immutably correlated with one another that the presence of one of necessity involves the presence of all the others; thus the presence of the columella does not involve the presence of the tabellæ, nor the dissepiments that of the septa. Had these units all been immutably correlated, then only one morphological series of corals would have been possible, and Carboniferous palæontology could then have been studied without tears. In actual fact the elements may be present or absent in varying combinations, and thus a wide variety of coral types may exist. The number possible is a matter for mathematical calculation. The real number may be smaller, for a coral consisting, for example, of tabulæ alone is inconceivable.

THE MEASUREMENT OF STRUCTURAL UNITS IN CORALS.

Not only do the structural units vary as to their presence or absence, but the individual elements themselves are also subject to perpetual change in quite definite directions.

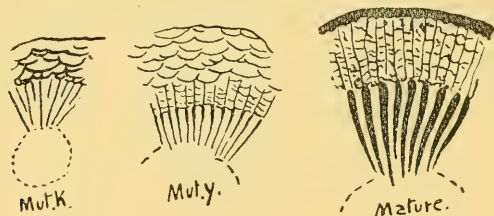


FIG. 5.—Portions of sections of mutations K, γ , δ from the gens *Caninia cylindrica* (after Vaughan).

A brief inspection of a number of coral-slices of several genera, or of different parts of the same individual, will show that the elements differ in the various slices. These differences may be sorted out and arranged in series. Thus the inner ends of the major septa (Fig. 5) may be withdrawn from or approximated towards the centre. Similarly the outer ends may extend to or be separated from the theca (Fig. 5). This incidentally furnishes an illustration of the same unit being affected by two divergent series of changes. In both cases the changes may be accurately recorded by measuring the distances of the inner and the outer ends of the septa from the epitheca. The figures may then be expressed as percentages of the average diameter of the coral.

Where minor septa have become units of sufficient prominence they, too, may be measured in the same way. For both kinds of septa the total number present is a feature of some importance.

The dissepiments occupy a wide or narrow zone which always lies in contact with the epitheca. The width of this zone is easily measured, and, again, may be expressed as a percentage of the coral diameter.

Many lamellæ are in reality the central continuation of the septa, from which they often become separated at the edge of the tabellar zone. New lamellæ, having no relationship to the septa, often arise between the old ones. The total number may be counted and recorded.

Not uncommonly the lamellæ and the central ends of the septa become curved in various degrees, and may even become strongly spiral or even crumpled. These differences, which may form one or more series of changes, do not admit of easy measurement. In such cases the method of procedure is to represent the main steps in the series from one extreme to the other by five or ten diagrams. The extremes are then taken to be 0 and 100 respectively, and thus the stages in the development of curvature, represented by the diagrams, can be expressed as percentages of the maximum curvature.

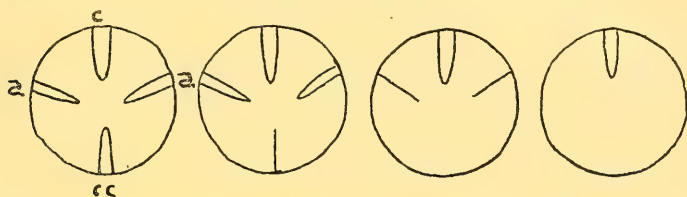


FIG. 6.—Diagrams representing some of the stages in the serial reduction of the fossulæ in Carboniferous corals. *c*. cardinal fossula, *cc*. counter-cardinal fossula, *a*. alar fossulæ.

This method of using a series of diagrams may be applied to differences exhibited by the columella. In some corals this unit is merely the central portion of a median partition, which stretches across the coral (Fig. 4 col.). In others this septum is broken on the cardinal side of the centre. In others, again, it is broken on the counter-cardinal side also. The columella also exhibits various degrees of thickening. The history of the columella, however, is not simple, and requires more discussion than the scope of this paper will allow.

The passage from bilateral to radial symmetry is an important direction of change which undoubtedly takes place in numerous quite separate lines of descent, and expresses itself with the help of several structural units, such as the major and minor septa and the fossulæ or depressions in the tabulæ.

The changes, in so far as they involve the fossulæ, range from the presence of four fossulæ (Fig. 6) in bilaterally symmetrical corals, through various stages in the reduction first of the counter-cardinal, and then of the alar, and finally of the cardinal fossulæ, to the complete absence of all four in the radially symmetrical corals. Along some lines the alar fossulæ go before the counter-cardinal one does. In either case diagrams, representing stages at different percentage intervals from one extreme to the other, may be drawn.

Of the major septa only four or six approximate to a radial

arrangement in a coral showing maximum bilateral symmetry (Fig. 7, *cs*, *ccs*, *a*). As the symmetry changes the percentage number of radial septa increases until all are radial. Even when major septa indicate only lingering traces of bilateral symmetry, the minor septa may still reveal it to a marked degree. These latter elements put in their first appearance on the counter-cardinal side of the section, and as their number increases they extend round to the cardinal side, until there are as many minor as there are major septa. The number of minor septa expressed as a percentage of the total number of major septa thus becomes another measure of the serial change from bilateral to radial symmetry.

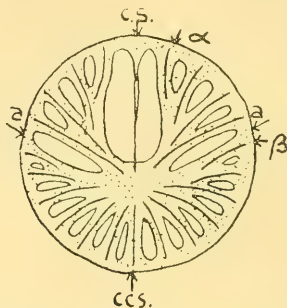


FIG. 7.—Section of *Zaphrentis delanouei* (after Carruthers, *Q.J.G.S.*, 1910, pl. xxxvii, fig. 3A). *cs.* cardinal septum, *c.c.s.* counter-cardinal septum, *a* the shortest septum in one of the cardinal quadrants, *β* the shortest septum in one of the counter-cardinal quadrants.

The following examples will serve to illustrate the way in which these numbers and percentages may be expressed graphically, and so be used for the solution of evolutionary problems. The measurements used here have all been made upon the published figure of easily accessible and important pieces of work. The examples chosen are useful as tests for, as well as illustrations of, the method. The first is from a paper containing a careful and detailed description of the development of one coral. The second is from another, by the same author, in which the evolution of a species is traced in a manner closely approaching the ideal, and results are attained which cannot be refuted. The third is a fair example of the practice of linking together in series, mutations which, in the opinion of a specialist, "are continuously related either in space or time."¹

EXAMPLE II : THE DEVELOPMENT OF *CANINIA CORNUCOPIÆ*.

On plate vi of Carruthers' paper² on the development of *Caninia cornucopiae*, figs. 1b to 1j represent slices cut across the coral at different levels from the apex to the calyx. They, therefore, record the changes which are passed through in development. Many

¹ Vaughan, *Quart. Journ. Geol. Soc.*, vol. lxi, 1905, p. 183.

² Carruthers, *GEOL. MAG.*, 1908, p. 158.

different measurements may be made, but only those which reflect distinct changes have been taken into account here. They are the following :—

(A) The percentage number of septa that have become distinctly radial in their arrangement. In addition to lying along a radius, this implies that they are equal in length.

(B) The number of minor septa expressed as a percentage of the total number of major septa.

(C) The reduction of the fossulæ.

(D) The percentage number of septa in the counter cardinal quadrants.

(E) The number of septa as a percentage of the total number in the adult.

(F) The diameter of the central space occupied by the septa.

(A) to (D) relate chiefly to changing symmetry.

(F) reflects both the progressive extension of the central area, which becomes occupied by tabulæ alone, and a gradual shortening of the septa themselves.

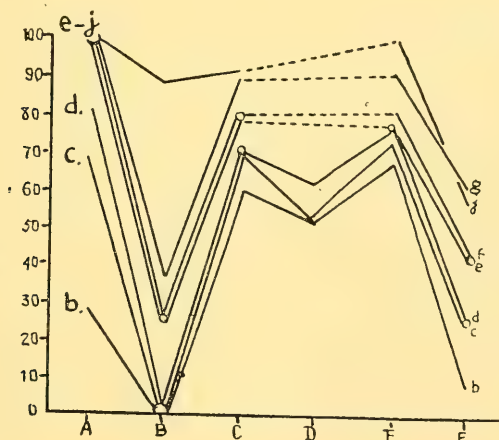


FIG. 8.—A series of graphs representing stages in the development of *Caninia cornucopiae*.

In Fig. 8 the line *b* represents the measurements on Mr. Carruthers' fig. 1*b*. This was the earliest stage in development described by him. The other lines correspond to his figs. 1*c* to 1*j* respectively.

It is at once evident that the graphs, though they are not parallel, develop out of one another in sequence; that is to say, that with one slight exception they do not cross one another. The slight exception is the crossing of *g* and *j* between E and F. In the absence of later stages than *j* it is impossible to explain this. It may be due either to a reversal of the direction of development, or to that fluctuation about a mean which characterizes an element that has

become stationary. In the absence of further evidence this may be neglected.

As already seen in Example I, taken from Palæozoic echinoids, the rate of change of any one element is not necessarily the same as that of any other element. Had the rates of change been equal the lines would have been parallel. Comparing A and B, it will be seen that while A changes rapidly from *b* to *d*, B is stationary. When A has reached its maximum development and has become stationary, B progresses by leaps and bounds. The facts almost suggest a principle which may be described as the conservation of developmental energy. It is as though the energy were limited, so that when it is being used freely on one element, another must develop slowly or become stationary.

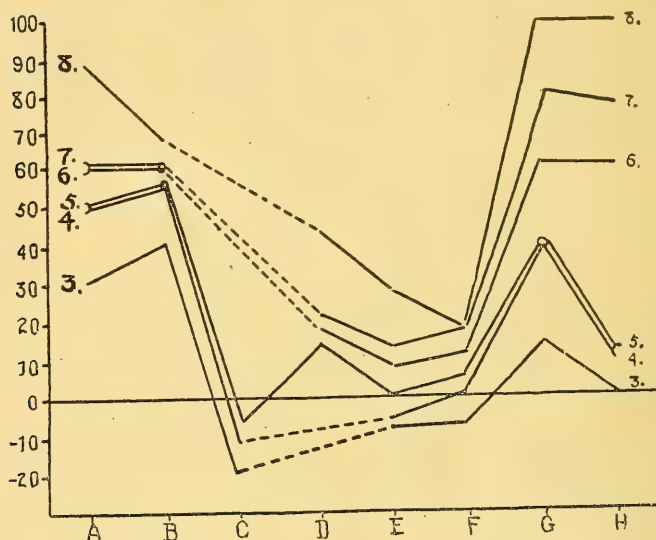


FIG. 9.—Series of graphs representing the stages in the evolution of *Zaphrentis delanouei*.

EXAMPLE III: THE EVOLUTION OF ZAPHRENTIS DELANOUEI.¹

As already indicated, this is one of those rare cases in which the palæontologist's dream of a perfectly worked out lineage is as near fulfilment as is humanly possible. That the series *delanouei*, *parallela*, *constricta*, and *disjuncta*, is a genetic series cannot be denied. The evidence adduced from the study of development, distribution, variation, and succession in the rocks is overwhelming. The measurements represented graphically in Fig. 9 were made upon the following figures on pl. xxxvii of Mr. Carruthers' paper:—

¹ Carruthers, *Quart. Journ. Geol. Soc.*, vol. lxvi, 1910, p. 523.

3a. <i>Zaphrentis delanouei</i> .	6a. <i>Zaphrentis disjuncta</i> (early).
4a. " <i>parallela</i> .	7a. " " (typical).
5a. " <i>constricta</i> .	8a. " " (advanced).

The changes measured were as follows:—

A. The reduction of the fossulæ.

B. The length of the cardinal fossulæ from the epitheca to central stereom, or when this has disappeared, to the inner end of the counter cardinal septum. This is expressed as a percentage of the diameter.

C. The width of the fossula at its inner end, expressed as a percentage of the diameter.

D. The distance between the inner ends of the alar septa, expressed as a percentage of the diameter. This reflects the progressive shortening of the septa and their withdrawal from the centre.

E. The percentage length of the shortest septum in the cardinal quadrants (cf. Fig. 7a).

F. The percentage length of the shortest septa in the counter-cardinal quadrants (Fig. 7β).

G. The reduction of the central stereom.

H. The percentage of free septa.

Measurements E to H call for further explanation.

Taking E and F first, at stage 3 (Fig. 9), the septa still exhibit a markedly pinnate arrangement. During the succeeding stages the shortest septum in each quadrant, viz. those which lie next to the cardinal and alar septa on the counter-cardinal side (Figs. 7a, β) undergo striking changes which reflect two important alterations affecting the coral as a whole.

The first or earlier alteration is the passage from a pinnate to a radial symmetry. Whilst this is taking place the short septa elongate until they are equal in length with the other septa.

The second and later alteration takes place when an advanced stage in the attainment of a radial symmetry has been reached. All the septa now begin to shorten and to withdraw simultaneously from the centre. This change is also shared by the four septa under consideration.

These four septa thus elongate during the earlier stages and shorten during the later stages of evolution. This reversal in the direction of change of these septa is most simply expressed in graphic form by placing the point of reversal on the zero line, and representing the changes which precede it below and those which follow above the line.

Turning now to G and H, in stage 3 (Fig. 9), there is a considerable deposit of stereom at the centre of the coral, which binds the inner ends of the septa together. With the progress of evolution the stereom becomes reduced in quantity and the septa gradually become liberated. This change can be expressed either in the form of a series of diagrams representing the reduction of the area of the stereom (G), or by figures giving the percentage of free septa (H).

If now the graphs of these measurements be examined (Fig. 9), it will be seen that the lines 3 to 8 follow one another in sequence and without crossing, so that the same conditions hold good for a phylogenetic as for an ontogenetic set of graphs. Again, the rate of change in one structural unit is not necessarily the same as for another, and thus the conception of the independence of the various serial changes receives further confirmation.

It is interesting to observe that in 4 and 5, in which a reversal of direction of change takes place in some elements, the other elements come temporarily to a standstill. Again, in 6 and 7, whilst G and H progress rapidly, A and B remain stationary. These facts seem to indicate the existence of a principle of the conservation of evolutionary energy.

EXAMPLE IV : THE GENUS *CANINIA CYLINDRICA*.¹

Another method of establishing lineages is resorted to when the material to hand is limited. It is based upon the quite reasonable assumption that a specialist on any group of fossils is thoroughly familiar with the various combinations of resemblances and differences of a wide range of types. This familiarity enables him to detect those forms which are so closely allied to one another that they must evidently belong to one genetic series, gens or lineage. Once he has established a reputation for reliability his conclusions are naturally accepted by his fellow-workers, until such a time as another specialist upon the same group arises to either refute or confirm his findings. The method of graphic representation explained above supplies an alternative means of testing the genetic affinity of apparently similar forms when the material is not abundant, and the investigator is not a specialist.

In the late Dr. Vaughan's paper on the Dinantian and Avonian he publishes a series of sections (pl. iii, figs. 1-5) across five corals, which he calls mutations K , β , Z , γ , δ (cf. fig. 5 above), and which he regards as a gens or a series of "continuously related" forms.

After making many different measurements of the elements in each of his five figures the following series of changes were found to be important and instructive :—

- (A) The number of minor septa.
- (B) The number of major septa.
- (C) The length of the major septa.
- (D) The distance of the outer ends of the septa from the epitheca.
- (E) The width of the dissepimental zone.

These measurements are reproduced in graphic form in Fig. 10. From this it will be seen that the graphs K , β , δ , fulfil all the requirements of a genetic series; that Z transgresses slightly across the other graphs, and presumably is not distantly removed from the

¹ Vaughan, *Quart. Journ. Geol. Soc.*, vol. lxxi, 1915, p. 36

series ; but that γ is very much out of accord with all the others, and therefore lies quite distinctly off the true line of descent.

GENERAL REMARKS.

In laying emphasis upon the principal of the independence of flow-lines of change in structural elements it is not intended to deny the principle of the correlation of parts. On the contrary, it is held that the wonderful correlation of parts, which characterize all organisms which survive the vicissitudes of ever-changing surroundings, is the outcome of a continual adjustment of the parts to one another. Such an adjustment can be attained only if the parts are free to change this way or that with independent velocities. Only by such independence, for example, could the five-toed primitive mammals have given rise to such diverse types of feet as those of the horse, the elephant, and the sloth.

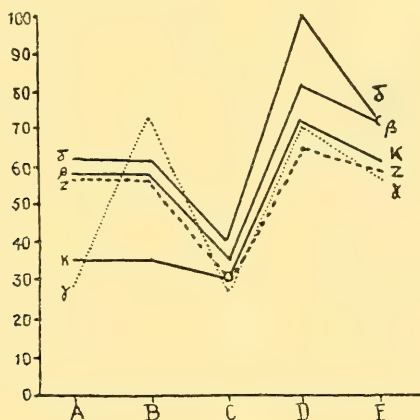


FIG. 10.—Series of graphs representing the mutations of the gens *Caninia cylindrica*.

Whilst a description of these three types of feet may be quite diagnostic of these three mammals, it is not diagnostic of the genetic series to which each belongs, for such a series exhibits continual change as it is followed through time. In this case, it is the direction and velocity of change in homologous parts which is diagnostic.

In palæontology the time factor is of supreme importance. On this account it is not the species, but the flow-lines of change, with or without clearly defined structural units, which provide the easiest points of attack for the study of evolutionary problems. Indeed, the separation, and the elucidation of the behaviour of these flow-lines, which clustered together constitute the lineages of various groups, is a necessary preliminary to the unravelling of phylogenies and the solving of problems in heredity.

As already shown, homologous units in separate genetic series

are frequently the subjects of the same limited range of changes. Owing to the varying rates of change of the elements in different lines of descent, the majority of varieties and species as a whole are quite distinguishable from one another. If, however, several elements happen to attain the same stages together in two or more of these lines a resemblance, often quite striking, arises between even distantly related organisms. This phenomenon finds expression in the terms "morphological equivalence", "homœomorphy", "convergence". If these same structures maintain the same relative rates of change, that is to say, if they become correlated with one another, then a series of homœomorphs will result. In any case the goals towards which the flow-lines of changes tend may be the same in quite divergent lines of descent. In the later history of several such lines it often happens that first one and then another homologous structural element reaches its goal, and morphological resemblance becomes dominant. The only escape from this blind alley of homœomorphy and convergence is either by extinction or by reversal of the direction of change.

Some of the phenomena dealt with above bring the palæontologist within hailing distance of the Mendelian experimenter; for both are approaching the same problem from different angles. It may not be out of place therefore to express some of the thoughts which a comparison of the results attained by both classes of workers suggests.

The accompanying table gives a summary of Mr. Carruthers' discoveries concerning the distribution of the mutational stages in the evolution of *Zaphrentis delanouei* in time and space. In considering the figures it must be borne in mind that the distinction between stages or mutations (Waagen non De Vries.) is arbitrary, and corresponds to no breaks in the series.

<i>Stratigraphical level.</i>	<i>Z. delanouei.</i>	<i>Z. parallela.</i>	<i>Z. constricta.</i>	<i>Z. disjuncta.</i>
Millstone Grit .	—	—	5	95
Upper Limestone	—	·3	16	83
Lower Limestone	·7	·3	69	28
Cementstone group . . .	69	30	1	—

TABLE II.—This shows the percentage number of representatives of each stage at each of the four main stratigraphical levels.

From this it is evident that all the stages had representatives at the lower limestone level. Similarly at other levels several stages were present. Evidently, therefore, varieties which are contemporaneous with one another, may give a true representation of the evolutionary stages; and the differences between homologous structural units, shown in them, may mark out the lines along which changes in the units flow.

The biologist draws the varieties upon which he experiments

from one stratigraphical level, namely the present. The relationship of his material to that of the palæontologist is evident from what has just been stated. It is like a cross-section of lineages which stretch back into the, to him, inaccessible past.

Mendelian experiments of necessity deal only with (differentiating) characters belonging to homologous parts, e.g. the end of a pod, pointed or rounded; the edge of a leaf, much or little serrated; the epidermis of a plant, smooth or hairy. They deal, therefore, not with separate structural units as such, but with certain stages in the changes which they undergo. Thus, the end of a pod is not only either pointed or rounded, every gradation between these two extremes may be found, provided all pods are taken into account. The fact that such gradations do occur to-day indicate that pointedness and roundness have not arisen suddenly but gradually during past ages. So, likewise, with the edge of the leaf, the epidermis of a plant, and many other homologous parts which have supplied material for experimentation.

Where such gradation exists, the experiments appear to deal with the extremes of the series which correspond with such percentages, as, say, 0 and 95 or 10 and 70 of the scheme explained in the earlier part of this paper. If this be the case, some, at least, of the Mendelian unit characters are merely stages in the serial changes of a structural unit.

The fact that structural unit A at stage 0 or 10, for example, can be removed and replaced by the same structural unit at stage 95 or 70 without producing any corresponding change in the elements B, C, D, etc., furnishes yet further confirmation of the view that serial changes in one element are independent of those in another.

The terms structural unit and element used so frequently above seem at first sight to be synonymous with Osborn's unit character or biocharacter.¹ In so far as he defines this as a separable unit in ontogeny and phylogeny, the two are the same. But in his definition he appears to regard the biocharacter as being the same as a Mendelian unit character. Now the unit in ontogeny and phylogeny is something which changes continuously. The Mendelian character, on the contrary, is something which is quite fixed, and, within the limits of experimentation, unchangeable. If it were not so the experimenter would lose his bearings in the multiplicity of his filial generations. The view adopted here therefore is that the Mendelian unit character is not merely a structural unit, but a structural unit at a certain stage of evolution. The experimenter does not exchange one structural unit for another, e.g. horns for ears, but a structural unit at one stage of evolution for a homologous unit at another stage, e.g. long staple and short staple in cotton, presence or absence of horns in cattle.

Once more, it may be allowable to emphasize the fact that it is

¹ H. F. Osborn, *American Naturalist*, 1917, p. 449.

not always possible to state what are the precise anatomical or histological constituents which make up the "structural unit" under consideration. A term seems to be needed which will stand for the phenomenon referred to in this paper under such phrases as a "unit series of changes", "flow-line of change", "direction of change". Even a clearly defined structural unit may be the subject of several different but definite directions of change in less closely related lineages, cf. the ambulacral areas of palæozoic and modern echinoids, or the feet of perissodactyles and artiodactyles.

Tallness and dwarfness in peas have become classical subjects for experimentation. These two features in peas seem to belong to the same order of phenomena as narrowness and broadness of skull in Titanotheres. These types of skull have been proved to arise gradually from skulls of median proportions.¹ Judging by the fact that peas of all statures between tall and short exist to-day it seems not improbable that the tall and short races must likewise have arisen gradually, during the passage of time, from a race of median stature. Be this as it may, the tall and short peas, with which the experiments were performed, are to-day distinct races; that is to say, they belong to different lineages which breed true and which for a period of time have been pursuing divergent lines of evolution in respect of stature. The experimenter crosses the races and transposes the tallness of one line to the other line, and by so doing produces a new race having the usual characters of the dwarf pea except as regards stature. The fact that he is able to do this suggests that a similar exchange, likewise resulting in the sudden appearance of a new race, could and did take place in nature, for during the early history of allied lineages it is reasonable to infer that they would be as mutually fertile as these two races of peas. Thus, in Fig. 10 it is conceivable that mutation χ was produced by a cross between a form similar to K and one in which there were few minor and many major septa. If that has been the case then χ , like the experimenter's new race of peas, had a dual ancestry. This is, of course, purely hypothetical, nevertheless, it illustrates one type of problem that the use of graphic methods in palæontology may hope to solve. Meanwhile, the results of Mendelian experimentation produce the uncomfortable feeling that a palæontologist tracing lineages of species, or even in some cases, of genera to common ancestors is pursuing a "will-o'-th'-wisp", that converging lines of descent run back, not into a point, but into a network of incipient lineages, in which structural elements as they change are shuffled across, like strands, from one thread to another, until several combinations of developmental stages have been hit upon which are both stable and mutually sterile.

My thanks are due to my colleagues, Mr. H. S. Holden and Mr. A. W. Richardson, for much free discussion of the subject matter of this paper and for many helpful criticisms and suggestions.

¹ Osborn, *Bull. Amer. Mus. Nat. Hist.*, 1902, pp. 77-89.

An Outline of Chinese Geology

By J. S. LEE, M.Sc., Birmingham.

(Concluded from p. 377.)

The apparent conflict in palæontological evidence is still more aggravated if the views of several able palæobotanists be taken into consideration. Plant-remains have been frequently found from the Shansian rocks in various parts of northern China. They amount to a copious flora. Numerous species are described by Newberry, Schenk, Abbado, Zeiller, Zalescky, and Yokoyama.¹ In some cases these writers agree in assigning the flora to the Upper Carboniferous. The presence of *Taniopteris multinervis*, which is said to have never been found in Europe below the Autunian stage, and a number of its allied species, such as *Lepidodendron gaudryi*, *Calamites* cf. *leioderma*, has, however, led Zeiller to conclude that the coal-bearing Shansian rocks in the Shan-si Province range from the highest Stephanian to the Lower Permian. Schenk also holds that the coal-bearing series of Kai-ping, eastern Chi-li, and that of Pen-hsi-hu, Manchuria, are of Permian age.

It is to be noted that the plant-remains occur in the strata closely associated with the coal seams; the coal seams usually occur above the limestone yielding the marine fossils, and are sometimes intercalated in it, but rarely found below it. When the coal seams occur above the limestone, the intervening rocks generally consist of sandstones and shales having a total thickness of less than 250 feet. It is therefore evident that even if we take the maximum thickness of rocks between the faunal and floral zones it can hardly be considered as sufficiently thick for representing such a long period of time as it would necessarily do if the fauna really belongs to the Lower Carboniferous. Suggestions have been made as to the possible existence of a stratigraphical break between the marine formation and the Productive Measures in the coal-fields of Shan-si and Shantung, but no known structural facts seem to support this idea. For future stratigraphical research the numerous species of Fusulinidea that occur in the marine limestone may yet prove to be of immense value as age-indicators. At present the presence of these Foraminifera, together with the flora, seems to justify the statement that the Shansian System represents a period not earlier than the Middle Carboniferous nor later than the youngest Permian.

With respect to the marine facies, it is best, under the light of our present knowledge, to take the development in eastern Yun-nan as a typical one. There the Anthracolithic Formation may be described as consisting of the following three series²:—

¹ *Smithsonian Contribution*, vol. xv, art. 4, pp. 121-3; *China*, vol. iv, pp. 211-44; *Palæont.*, vol. xxxi, 1885, pp. 163-82; *Palæont. italica*, vol. v, 1900, pp. 125-44; *Ann. d. Min.*, vol. xix, sér. ix, 1901, pp. 431-53; *Verh. K. Russ. M. Gesell.*, ser. II, vol. xlii, pp. 385-98; *Journ. Coll. Sci. Imp. Univ. Tokyo*, No. 8, 1908, pp. 1-18.

² Deprat, op. cit., pp. 98-174.

- c. Upper or Volcanic Series. Bedded andesite, basaltic lava, tuff, and other volcanic rocks followed downwards by a massive conglomerate and sandstone aggregating to a thickness of more than 1,800 feet; unconformably overlain by the Trias.

Unconformity

- b. Middle or Fusulinidea Limestone Series. Light- and dark-grey limestones, locally sandy; total thickness about 3,800 feet; crowded with Fusulinidea. Faunistically this series can be subdivided into three parts: in the upper part the species *Doliolina lepida* abounds, *Neoschwagerina multiseptata*, *N. (Sumatrina) annæ*, *Fusulina exilis*, *Schwagerina verbeeki* are also of frequent occurrence; in the middle part a Lower Permian fauna of Brachiopods predominates over the Fusulinidea, *Spirifer blassi*, *Spirigerella grandis*, *Camarophoria globulina*, *Hemiptychinax sparsiplicata*, *Martiniopsis inflata*, *Productus gratosus* being the more characteristic species; in the lower part *Neoschwagerina craticulifera*, *Schwagerina princeps*, *Fusulina multisepta*, *F. brevicula*, *F. regularis*, etc., occur in association with a number of species of Brachiopods belonging to the Upper Carboniferous, e.g. *Productus cf. subcostatus*, *P. cf. compressus*, *Reticularia lineata*.

Unconformity

- a. Lower Series. Limestones followed downwards by coal-bearing sandstones, again limestone and then shales and sandstones; yielding *Spirifer mosquensis*, *Spiriferina cristata*, *Athyris cf. subtilita*, *Productus glabra*, *P. cora*, *P. striata*, *P. undatus*, *Productella spinulosa*, *Chonetes papilionacea*, *Orthothetes crenistria*, and many species of Gastropods and Lamellibranchs indicative of Muscovian and Dinantian or Middle and Lower Carboniferous age.

These series are traceable to a large extent outside the area of eastern Yun-nan. The Lower Series, with a fauna of Brachiopods, Lamellibranchs, and Gastropods, extends northward along the south-eastern border of the Great Red Basin of Su-chuan, passing the districts of Lan-mou-tchang, Wei-ning, in the province of Kwei-chou; the coal-fields of Nan-chuan, south-eastern Su-chuan¹; and reaching the Shao-yang district² in central Hu-nan. *Orthothetes crenistria* appears to be one of the widely distributed species in the Lower Series. It is a remarkable fact that even in the limestones of this series none of the Fusulinidea which are so abundant in the Middle Series has yet been found.

The Middle Series, with its characteristic faunas of Fusulinidea and Brachiopods closely related to the fauna of the Middle Productus Limestone of the Salt Range, has been observed in the neighbourhood of Ta-li, Yung-tshang, Tze-de, Ngan-tshang-po, western Yun-nan; Ho-chang, Tung-tze, Sung-kan, north-western Kwei-chou; the Yakarlo district on the Tibetan border.³ The limestone that forms a long range running from the north of Ta-li to the west of Ta-tsien-lu as observed by Loczy; the "Doliolina Formation"⁴ that occurs in western Kan-su and the Semenow Mountain, south of the Kuku-nor;

¹ *China*, vol. v, pp. 77, 81-6.

² *Journ. Geol. Soc. Tokyo*, No. 263, p. 84, 1915; *idem*, No. 265, p. 139.

³ Leclère, op. cit., pp. 30-1; Loczy, op. cit., pp. 188, 202; *China*, vol. v, pp. 167-75.

⁴ *Durch Asien*, vol. ii, pt. ii, pp. 38, 116, 204-5.

and the *Fusulina*-bearing limestone in the Nan-shan Ranges undoubtedly represent at least a part of the Middle Series.

The Upper Series, though apparently less extensive, is nevertheless known in the Tang-tang district, on the northern border of Yun-nan, where it is underlain by the "Permo-Carboniferous Limestone" (= the Middle Series) and overlain by the Trias.¹ The pyroclastic rocks of the Sang-hu-shan,² south-eastern Hu-peh, that overlies the Permian coal-bearing series, is in all probability a representative of the Upper Series in the middle Yang-tze Valley.

The post-Middle Carboniferous and pre-Uralian unconformity deserves special notice. It is by no means a phenomenon limited to eastern Yun-nan. The important rôle that it plays in determining the structure of western China may be realized if we examine Obrutchov's report from the Nan-shan and Loczy's report from the mountains of western Su-chuan and western Yun-nan.³

In central China the unconformity, however, does not appear to exist. Willis and Blackwelder, in the course of their reconnaissance in western Hu-peh, distinguished a dark bituminous limestone, the Wu-shan Limestone,⁴ representing, as may be inferred from the fossils so far obtained, the period ranging from the Lower Carboniferous to at least the Lower Permian. Further west similar limestones⁵ have been found by Richthofen to the south of the Ning-kiang, and by Obrutchov in the valley of the Pei-sui-kiang.

The region of the lower Yang-tze Valley (below Kiu-kiang) affords good examples for showing the mixed development of the two facies of the Anthracolithic Formation. In this region we have the continental deposit of the northern type with coal seams as well as the massive *Fusulinidea* limestone of the south-west. From the record of Richthofen's observations and the *Record of the Work of the Geological Institute* it appears that the Carboniferous-Permian rocks in the lower Yang-tze Valley can be generally divided into three series in the following order:—

- c. Upper or Coal-bearing Series. Sandstone and coal-bearing shale with intercalated marine limestone, yielding a fauna related to that of the Middle *Productus* Limestone of the Salt Range and of Sumatra. The more characteristic species are *Reticularia lineata*, *R. waageni*, *Productus sumatrensis*, *P. longispinus*, *Richthofenia sinensis*, *Lyttonia richthofeni*, *Orthoceras* cf. *cyclophorum*, *Fusulina cylindrica*, *Rhombopora lepidendroides*, *Aviculopecten M'Coyi*, etc.

This series is sometimes represented by a barren sandstone, as in the vicinity of the Si-hu, near Hang-chou.

- b. Middle or *Fusulinidea* Limestone Series. Bituminous limestone containing layers of flints and many species of *Fusulina* and *Schwagerina* characteristic of the Middle Series of the Anthracolithic Formation.

¹ *Journ. Coll. Sci. Imp. Univ. Tokyo*, vol. xxi, art. 9.

² *China*, vol. iii, p. 521.

³ Loczy, op. cit., vol. i, pp. 692-746; Suess, *La Face de la Terre*, iii, pp. 277, 293.

⁴ Willis, op. cit., vol. i, pt. i, pp. 274-6.

⁵ *China*, vol. ii, pp. 600-1.

- a. Lower Series. Massive conglomerate and sandstone immediately underlain by a bituminous limestone with Lower Carboniferous fossils, e.g. *Lonsdaleia floriformis*, *L. papillata*, *Zaphrentis spinulosa*, *Syringopora ramulosa*, *Hallia* (*Caninia*) *gigantea*, *Fistulipora minor*.

Richthofen describes a classical section of this series in the Hsi-hsia-shan, near Nan-king.

It is highly probable that these three series do not exactly correspond to those of eastern Yun-nan. Apparently either the whole or the lower part of the Upper Series described here is equivalent to the Middle Series of eastern Yun-nan. That is to say, only the lower part of the Fusulinidea Limestone of south-western China is present in the lower Yang-tze Valley. The upper part of the Lower Series, namely, the conglomerate and sandstone, possibly corresponds in time to the post-Middle Carboniferous and pre-Uralian unconformity already mentioned.

Closely related to the Anthracolithic Formation both in point of time and space, are several series of rocks in China that still evade our classification. In the Sin-tai Basin, western Shan-tung, Blackwelder distinguishes a Sintai Series consisting of sandstones and other kinds of terrestrial deposit. In view of the fact that the Sintai Series overlies the Poshan Series, Blackwelder regards the former as a Permo-Mesozoic formation. Plant-remains that have been obtained from this series generally indicate a Liassic age. The thickness of the series, according to Richthofen, amounts to about 1,400 feet, and according to Blackwelder still less. It therefore appears to be doubtful whether even the lowest part of the Sintai Series should be assigned to the transitional period from the Palæozoic to the Mesozoic. The Supra-coal Sandstone, a barren, massive sandstone overlying the Shansian Productive Measures in many places of northern and north-western China, is in all probability a true Permo-Mesozoic representative. In central China two series of Permo-Mesozoic rocks are known: the one is the Kuei-chou Series,¹ consisting of sandstones, shales with subordinate bands of limestones and layers of coal, and has yielded *Dielasma* cf. *elongatum*, *Aviculopecten* (?) *richthofeni*, crinoidal fragments, foraminiferal tests, *Nilssonina*, *Podozamites*, *Asplenium*, etc. It is frequently exposed in the Ta-ning-ho valley, western Hu-peh and eastern Su-chuan. The other is a coal-bearing shale of Hwang-i-kang,² in the lower part of the Liu-ho valley, eastern Hu-nan, where Richthofen collected a peculiar molluscan fauna including the species *Aviculopecten coxanus*, *Pecten alberti*, and several species of *Schizodus* and *Bellerophon*.

About the Carboniferous-Permian rocks in China our knowledge is at present comparatively more advanced, and therefore a more precise interpretation of China's geological history during that period can be here attempted. In the early Carboniferous time the

¹ Willis, op. cit., vol. i, pt. i, pp. 277-83.

² Fréchet, *China*, vol. v, pp. 184-94.

whole of northern China was still a continent being eroded to a peneplain of aged type. A sea of moderate depth surrounded the western and the southern sides of the continent with the coastal line extending from the south of the Bardoun Valley,¹ in Mongolia, to the west of Kan-su, and then sweeping round along the northern side of the present Tsing-ling Range. Thence southward, the sea either spread over the whole area of the Great Red Basin of Su-chuan or only passed along its south-eastern border, and finally entered the province of Yun-nan. In this direction it could not have been very deep, for the sediment that it received was largely terrigenous.

The Lower Carboniferous sea did not rest long in the position as outlined above. Towards the later part of the Dinantian or the early Muscovian epoch it advanced in the north-easterly direction, turning the whole of northern China that had stood as a continent since the Devonian period into a vast ocean.

As the Muscovian epoch drew near its end, geo-dynamical forces made a grand display in the theatre of Central Asia. Folding and thrusting were accompanied by the eruption of andesitic, rhyolitic, and basaltic lava and intrusion of sills and dykes. The whole of western China, from the Nan-shan region to eastern Yun-nan, which had been under the Lower Carboniferous sea, was thereby lifted above the water. The north-eastern part of the country, however, does not appear to have been involved in this revolutionary disturbance. No sooner had the upheaval died out, than the Uralian or the Upper Carboniferous transgression took place; once more western China was submerged under deep water in which flourished a pelagic fauna. The transgression evidently progressed side by side with the formation of the Hercynian Chains, and the separation of the Indo-African Continent from the northern Eurasian Continent. Between these two continents lay the transgressive Uralian water. The fact that the Fusulina Limestone (= Fusulinidea Limestone) stretches across the Asiatic continent from western China to Egypt, i.e. in the equatorial direction, demonstrates with force such a parallel upheaval and depression.

While land and water were undergoing rearrangement in the world at large in consequence of the Hercynian disturbance, the formation of the thick coal was well under its way in northern and central China. After a period of oscillatory movement of the sea-floor during the Permo-Carboniferous time, the sea again started to retreat southwards, carrying with it estuarine conditions and depositing once more coal seams in the south-eastern provinces. Then there followed another mighty movement of orogenic as well as epeirogenic nature.

As the result of the last-mentioned movement, China proper was bodily elevated and secondarily folded probably in the Sinian direction, viz. north-east to south-west. Inland seas covered the north, while lagoons and salt lakes were formed in the south. In these

¹ Wenjukoff, "Calcaire carb. inférieure, etc.": *Verh. Kais. russ. mineralog. Gesell.*, vol. xxv, 1888.

waters were deposited the Supra-coal Sandstone of northern China, the coal-bearing series of eastern Hu-nan, the Permian gypseous deposit of the south-western provinces. Volcanic eruptions broke out at least in three or four different centres, namely, north-eastern Yun-nan, south-eastern Hu-peh, western Shan-tung, and probably in the vicinity of Nan-king. The enormous masses of granite and porphyry in south-eastern China, western Su-chuan, and at a number of localities in the middle Yang-tze Valley at least partly arrived during this period of unrest.

Owing to the shallow water conditions, the pelagic fauna that had flourished during the Middle Permian time was no longer able to survive in China. Littoral forms, however, thrived in places. Their affinities generally indicate the transition of life from the Palæozoic to the Mesozoic. Following such a change of fauna and a corresponding change of flora, the Triassic period gradually set in. Apart from minor stratigraphical breaks, as indicated by local unconformities in the south-western provinces, there appear no signs of remarkable earth-movement in China to define the beginning of the Mesozoic Era.

TRIASSIC AND JURASSIC.

Mesozoic rocks are developed *par excellence* in the Great Red Basin of Su-chuan and in the areas immediately to the south and east of it. Elsewhere in China they are only known to occur in smaller isolated basins, but are, nevertheless, widely distributed.

With regard to the Trias, very little is known in northern China. If its presence be assumed—we have some reason to do so—its representative must be sought in the upper part of the Supra-coal Sandstone and the similar shallow water or even terrestrial deposits. The rocks are usually destitute of fossils. Only two exceptional cases are known: Obrutchev found, near the village of San-shi-li-pu,¹ Shen-si, *Danaöpsis hughesii* (Middle Gondwana) occurring in association with representatives of the *Glossopteris* flora, such as *Neograthiopsis hislopi* and *Cordaitea* leaves. Brongniart² describes a flora collected from Tin-kia-po, southern Shan-si, belonging either to the Upper Trias or to the Lower Jurassic.

In contrast to the case of northern China we have in the south-western provinces several fossiliferous series of Triassic rocks. Information from Kwei-chou and Yun-nan seem to show that the Trias is more or less similarly developed throughout a greater part of these provinces,³ and generally consists of the following three conformable series:—

Upper Trias. Coal-bearing sandstone followed downwards by soft marls; containing *Trachyceras fasciger*, *Megaphyllites lantenoi*, *Pseudomonotis plicatuloides*, *Loxonema* cf. *subornata*, *Dictyophyllum exile*,

¹ *Denkschr. Akad. Wien*, vol. lxx, 1901, pp. 139–54.

² *Bull. Soc. Géol. France*, sér. III, vol. xxvii, 1899, pp. 499–520.

³ Deprat, op. cit., pp. 175–219. Leclère, op. cit., pp. 34–5, 38–9. Koken, *N. J. f. M.G.*, vol. i, pp. 186–215.

Glossopteris indica, *Anomozamites inconstans*, *Clathropteris platyphylla*.

Middle Trias. Series of limestones with intercalated marls and a few sandstones, yielding a typical Muschelkalk and St. Cassian fauna, including the species *Naticopsis undularia*, *Myophoria elegans*, *Torquemia difformis*, *Encrinurus liliiformis*.

Lower Trias. Variegated marls and sandstones with *Myophoria*, *Anoplophora*, *Lingula metensis*, etc.

The succession of the Triassic rocks in the Great Red Basin of Su-chuan and its neighbouring areas appears to be comparable with the above-described sequence, namely, a calcareous series intervening between two argillaceo-arenaceous series.¹ On the northern border of the basin the lower argillaceo-arenaceous series seems, according to Richthofen's report, to be absent.²

True marine formation of Lower Triassic age is definitely known in China only in two places³: Leclère found a hard, dark limestone near Kwei-yang (about long. 106° 40' E., lat. 26° 25' N.) and Kai-tshou (about long. 107° E., lat. 27° N.) yielding fossils that are related to the fauna of the Lower Ceratites Limestone of Indo-China. Futterer observed a limestone containing *Xenodiscus*, *Lecanites*, and being conformably succeeded downwards by a series of limestones, including the Doliolina Formation.

Jurassic rocks occur⁴ in the Sin-tai, Wei-hsien, Putschi basins, western Shan-tung; the Lai-yang Basin, eastern Shan-tung; the Tsaitang and Tatung Basin, northern Shan-si and north-western Chi-li; the Kuei-chou Basin, eastern Su-chuan; the Great Red Basin of Su-chuan; and the Yuan-kiang Valley, Kiang-si. They are generally composed of sandstones and shales frequently intercalated with seams of coal of high economic value. Several varieties of *Podozamites lanceolatus*, together with *Asplenium whitbyensis* and other species of Liassic plant, are of frequent occurrence in the above-mentioned places. Dr. A. Smith Woodward describes several species of *Lycoptera* from Layang-hsien,⁵ Shan-tung, and regards them as belonging to the Lower Jurassic.

A Jurassic dolomite containing *Pleuromya* and *Hologyra*? is reported to occur in the Jao-pu district, south of Tchen-ning (Kwei-chou). It attains a thickness of more than 600 feet. According to Leclère the dolomite is underlain, near the Blue River, by a Rhætic coal-bearing series. The limestone that forms plateaus between Kwang-si and Kwei-chou, north of Jao-mong, is tentatively attributed to the same formation.

In the Tatung Basin and on the western border of the Great Red

¹ Abendanon, *Zeits. d. d. Geol. Gesell.*, vol. lix, pp. 197–203.

² *China*, vol. ii, p. 603.

³ Leclère, loc. cit.; Futterer, *Durch Asien*, vol. iii, p. 131.

⁴ Lorenz, op. cit.; *China*, vol. ii, pp. 193, 208, 292–9, 351–9; *idem*, vol. iii, p. 104; *Denkschr. Akad. Wien*, vol. lxx, pp. 139–54; *Palæont.*, vol. xxxi, pp. 163–82; *Journ. Coll. Sci. Imp. Univ. Tokyo*, vol. xxi, art. 9.

⁵ *Catalogue of Fossil Fishes Brit. Mus.*, pt. iv, p. 3. The writer believes that the word "Layang-hsien" should be spelt as "Laiyang-hsien".

Basin of Su-chuan the Jurassic rests unconformably upon the older rocks; while inside the Red Basin and in the Kuei-chou Basin it is apparently conformable with the overlying and underlying rocks.

As previously remarked, during the transitional period from the Palæozoic to the Mesozoic a widespread and far-reaching change in physiography and physiographical conditions seems to have induced a rapid evolution of fauna and flora in China as in other parts of the globe. The physical change in China is, however, as a rule, neither indicated by a sharp contrast in the lithological character of the rocks formed during the period, nor by an unconformity which extends over a large area. Subaerial denudation on the lands proceeded simultaneously with the continuous deposition in their neighbouring waters. In this way the several Permo-Mesozoic series were presumably formed.

During the Lower Triassic time the Tsing-ling Range apparently stood well above the rest of the country. Its general trend could not have been very different from what it is to-day. By this range the shallow inland sea in the north was separated from an arm of the open ocean, which covered eastern Su-chuan, western Hu-peh, parts of Hu-nan and Kwei-chou, and eastern Yun-nan.

On the arrival of the Muschelkalk epoch the open Triassic ocean with a pelagic fauna made a decisive move from the Himalaya region towards the north-east, and succeeded, at least, in invading south-western China. The formation of the Middle Triassic Limestone was no doubt due to the introduction of true marine conditions. As the Middle Triassic sea started to retreat towards the south-west, estuaries and lagoons naturally came into existence. In these waters were deposited the Rhætic coal-bearing series. Towards the end of the Rhætic epoch south-western China again started to sink, resulting in the formation of the Jurassic dolomite, but many parts of western China gradually rose above the water. The separation of a huge lake, the Lake of Su-chuan, from the open sea had its initiation in all probability at this time.

The climate was then suitable for the growth of coal-making vegetation, and consequently coal seams were laid down in the lake during the Liassic time. Owing to occasionally excessive evaporation the water in the Lake of Su-chuan became highly saline; eventually seams of gypsum and rock salt were deposited. Under such climatic conditions, and in a water so heavily charged with macerated vegetable matter, it is readily imaginable that minute organisms multiplied themselves at an enormous rate when the water was less saline. Much of the mother substance of the petroleum in Su-chuan may have had its origin in this way.¹ Many of the depressed areas in northern China were likewise covered by inland waters, in which coal-bearing rocks were deposited. The flora that then thrived in China was closely related to that of Siberia and Spitzbergen, showing that these countries were attached to one

¹ W. S. Boulton, Presidential Address to Brit. Assoc. Adv. Sci., Section C, Newcastle-on-Tyne, 1916, p. 12.

and the same continent—the Angara Continent¹—in the Jurassic time.

POST-JURASSIC.

The period extending from the latter part of the Jurassic down to the present day is poorly represented in China by sedimentary record. The occurrence of a few *Unio* and *Cyrena* related to the Wealden fauna,² and one or two species of Cretaceous? plants³ in the Great Red Basin of Su-chuan, makes it highly probable that the Cretaceous period is there represented by a series of sandstones and clay-rocks as reported by Richthofen, Abendanon, and Cremer from eastern Su-chuan. This series is underlain by the coal-bearing Jurassic formation and overlain by a group of red sandstones of Tertiary age. No marine Cretaceous formation has been found in China proper, nor does it seem to occur in that part of the world.

Tertiary and Quarternary rocks are widely distributed in China, and attain a considerable thickness in places. With respect to their lithology, five groups are recognizable. They are enumerated below irrespective of the order of their formation:—

- (1) Coal-bearing, sandy, and clayey rocks occurring in the graben of the Liao-ho, Manchuria; and in the Mong-tzeu and other basins, Yun-nan.
- (2) A group of red sandstones, known as the Young Red Sandstone, often containing intercalated marly layers and basal conglomerate; widely distributed all over the Great Red Basin of Su-chuan, in the provinces of Hu-nan, Kwei-chow, Kwang-tung, Kiang-si, An-hwei, Hu-peh, Ho-nan, Shen-si, Kan-su. They are reported to occur on the high mountains of the Tsing-ling and in the valleys of the Nan-shan. Several local names have been proposed: Loczy calls it the Flysch-like sandstone in the mountainous area of western Su-chuan, Richthofen calls it the "Cover Sandstone" (Deckesandstein) in the province of Hu-nan. These rocks generally strike east-west or north-south except in the intermountain valleys of the high ranges where its dip, as a rule, conforms with the slope of the range against which it laps. Mammalian remains, largely belonging to the Pliocene but rarely to the Quaternary,⁴ are frequently found in the bedded rocks of this series or in the caves formed in it.
- (3) The Gobi or Han-hai⁵ Series consisting of soft sandstones, clays, and loose conglomerate; well developed in north-western China and Mongolia; merging, in some cases, into the Young Red Sandstone.
- (4) A conglomerate significantly developed on the down-throw sides of great normal faults in northern China, e.g. in the Ning-shan Basin, Shan-si, and in the Wen-ho Valley, Shan-tung. Willis and Blackwelder name it the Wen-ho Conglomerate.⁶

¹ Suess, *The Face of the Earth*, vol. iii, p. 19.

² Frech, *China*, vol. v, pp. 221-5.

³ *Journ. Coll. Sci. Imp. Univ. Tokyo*, vol. xxi, art. 9.

⁴ Owen, "On Fossil Remains of Mammals found in China": *Quart. Journ. Geol. Soc.*, vol. xxvi, pp. 417-34. Schlosser, "Die fossilen Säugethiere Chinas": *Centralbl. f. M.G.*, 1902, 529-35; *Abh. K. bay. Akad. Wiss.*, vol. xxii, 1903, pp. 1-221. Koken, "Ueber fossile Säugethiere aus China": *Palæont. Abh.*, vol. iii, 1885.

⁵ *Peter. Mitt.*, vol. xlv, 1900, pp. 22-3.

⁶ Willis, *op. cit.*, pp. 57-8.

- (5) The Loess or Hwang-tu composed of a soft, homogeneous, clayey material often with suggestions of stratification, occasionally interbedded with sands and clays; capping high mountain ranges and forming extensive plains in northern China. The structure of the Loess is singularly vertical; for instance, peculiar tubes sometimes as small as rootlets and sometimes as large as organ pipes frequently traverse the rock upwards and downwards.

Continental China has experienced much change since the later part of the Jurassic time. The succession of the more important events is briefly as follows: As the Jurassic seas receded both northward and southward from China proper, forces of denudation began to operate in full swing. Mountain ranges in central China were to a large extent planed down. The material thus produced was washed off into the neighbouring valleys and basins, such as the Great Red Basin of Su-chuan and others. The whole country, which presumably possessed a strong relief in the early part of the Jurassic period, gradually became a vast expanse of tableland. By the Cretaceous time China proper was completely reduced to a mature peneplain. Nevertheless, a broad epeirogenic swell seems to have continued to uplift the country in a steadfast manner, for even the world-wide Cenomanian transgression did not invade China any further than the southern part of Tibet.

Towards mid-Tertiary time the prolonged tranquillity was broken by a violent attack of orogenic movement from the south. The Alps of the Himalaya rose to a great altitude to the west of China; the Tsing-ling and Nan-ling ranges attained their lofty attitude across the central and the southern part of the country; large blocks of strata were faulted down in northern China to the extent of 10,000 feet or more; fissures or vein eruptions ejecting enormous quantities of basaltic lava were rampant in southern Mongolia, Shan-tung, and northern Kiang-su, answering to their comrades that were then fully active in Iceland and north-western Britain. Thus the process of erosion once more became vigorous.

The scenery of China was then quite different to the aged peneplain of the Cretaceous and early Tertiary time. Salt basins and intermountain lakes existed in all provinces. Such a varied type of scenery and other physical conditions evidently attracted the wandering beasts from various parts of the globe. The plateaus and open plains were peopled by the *Hipparion* fauna, while the forests and swamps were inhabited by the *Suidæ* or deer and swine-like animals. Their ancestors may have lived in Europe and North America, as shown by the presence of antelopes, *Cervus*, *Tylopoda*, etc., and their allies certainly scattered all over India and Persia.

Inevitably the lakes and basins were rapidly filled up by material derived from the mountains and highlands resulting in the formation of the Young Red Sandstone. Side by side, the deposition of the Gobi Series in north-western China turned the shallow inland sea into a vast plain dotted over with a large number of saline lakes. This region well deserves the name "Han-hai" or the Dry Sea.

As the result of the disappearance of inland waters, the atmosphere of northern and north-western China became arid. At the end of the Pliocene or the beginning of the Pleistocene time aeolian conditions prevailed. The decomposed rock-material was blown about and spread far and wide over hills and valleys. Thus the formation of the Loess began, and has continued down to the present day. It is uncertain whether there was a general lowering of temperature during this period in China¹ as in north-western Europe and North America; for even if the climate was severely cold, the aridity of the atmosphere could not have allowed the existence of large glaciers. The absence of a large mass of ice in Eastern Siberia to-day, in spite of the Arctic temperature, well illustrates such a case.

Since the mid-Tertiary movement hypogene geological forces have by no means become dormant; for we clearly see that the Young Red Sandstone and even the river deposit in the lower Yang-tze Valley are generally tilted. According to Mr. V. K. Ting the Loess in the Ssue-hua-shan and other districts, south-western Chi-li, is affected by a basaltic igneous rock. Apart from such stratigraphical evidence there is to be noted another class of phenomena—phenomena belonging to the physiographical domain—which, when carefully analysed, would undoubtedly throw light upon the problem of recent earth-movement in China. For the want of space, here we can only refer to one or two important points.

Let us follow for the moment the courses of the Hwang-ho and the Yang-tze-kiang. The fact that both of these rivers flow in their middle courses towards the central mountainous area, the Tsing-ling Range, is sufficiently significant to claim our consideration. If Pumpelly's diagram² illustrating the prehistoric course of the Hwang-ho be based on good authority, then the Hwang-ho must have travelled at one time through northern Shan-si and north-western Chi-li. The huge delta that spreads in front of small streams from the mountains to the north-west of the Plain of Peking, as described by G. F. Wright,³ appears to signify the previous existence of a powerful river, and therefore may be taken as a specific feature that tends to support Pumpelly's hypothetical diagram. Along the northern foot of the Ta-hwa-shan the Loess is apparently affected by the Ta-hwa fault which is, without doubt, a continuation of the famous Wei-ho fault. It then seems highly probable that the southerly course of the middle Hwang-ho has been determined by an uprise in north-eastern Chi-li and the downthrow of the Shansian block against the Tsing-ling Range, owing to the continued development of the Ta-hwa-Weiho fault. The "Universal Deluge" in northern China, before Emperor Yue (about 2700 B.C.) accomplished his great engineering feat at Long-menn (about long. 100° 10' E.,

¹ Cf. Geikie, *The Great Ice Age*, p. 402.

² Pumpelly, *op. cit.*, pl. v, map xi.

³ *Quart. Journ. Geol. Soc.*, vol. lvii, p. 244.

lat. 34° 40' N.), might have been partially due to such a dramatic physiographical change that had upset the pre-existing drainage systems. The fact that ancient seaports on the coast of Pe-chi-li are now found many miles inland is also in favour of this argument.

In the eastern part of the Great Red Basin of Su-chuan the Yangtze flows towards north-north-east in spite of the increasing mean altitude of land towards that direction. Clearly then the middle part of the river, which cut into the late Tertiary or even Quaternary sandstones, must be antecedent to the recent upheaval of the Tsingling area.

It is hoped that these working hypotheses drawn from very incomplete data may serve to arouse the interest of field geologists, by whose accurate record of detailed observations alone the question of their acceptance or rejection may be finally settled.

In spite of the great demand of space, the writer cannot let this opportunity pass without expressing his gratitude to Professor W. S. Boulton for his college training, especially during the preparation of a thesis of which the present paper is a precis; and his obligation to Dr. L. J. Wills, M.A., who cordially made several valuable suggestions and criticisms relating to the arrangement of material in this paper before it was put in the present form.

Morphological Studies on the Echinoidea Holectypoida and their Allies.

XI. *CONULOPYRINA ANOMALA*, A NEW TYPE OF THE *ECHINONĒIDÆ*.

By HERBERT L. HAWKINS, D.Sc., F.G.S., Professor of Geology,
University College, Reading.

(PLATE VII.)

AMONG the Echinoids from the Limestone Lenticles of Shenley Hill (Leighton Buzzard), sent to me from the Sedgwick Museum, Cambridge (see *GEOL. MAG.*, Vol. LVIII, 1921, p. 57), one specimen of the many Pyriniform examples at once attracted attention by its preservation, relatively large size, and superficial resemblance to *Holectypus*. A brief comment on the specimen (No. 3 of the series) was made in the note already cited; further and more detailed examination, preceded by removal of matrix, has revealed additional features of much interest. Though averse to diagnosis of new genera or species based on single specimens, I have felt compelled to adopt that course in this case, in default of acquaintance with any described types to which the Shenley Echinoid could be assimilated. It is quite likely that other specimens, congeneric if not conspecific, may exist in collections; according to their preservation or the idiosyncrasy of individuals they may be labelled *Holectypus*, *Conulus*, or *Pyrina* with equal probability. It is even possible that some of the numerous species of *Pyrina* (including *Pseudopyrina*

and *Globator*), already described, may be referable to the genus here introduced; but more details of morphology than are often supplied in systematic diagnoses and figures are needed before order can come out of the chaotic series of Cretaceous Echinonēidæ.

I am convinced that the shape of the test is a feature of practically no importance in specific determination in the group; while even the position of the periproct is reliable only when specimens of the same size from accurately determined horizons are compared. The apical system shows a remarkable constancy of structure throughout the family, and so is useless for detailed taxonomy. The obliquity or symmetry of the peristome is another morphological character often invoked as a generic criterion; but I have yet to find a specimen of *Conulus* without some degree of asymmetry in that aperture. There remain but two external characters for comparison, the surface-ornament and ambulacral structure. Both of these demand good preservation for detection, and patient study for appreciation; the latter attribute has too often been lacking in descriptions (and particularly in drawings) purporting to represent these details.

In the note introductory to this series of papers (GEOL. MAG., 1917, p. 161), I laid emphasis on the essential conservatism of the Holoctypoida, and the systematic difficulties thereby engendered. In no family of the order is this static quality of essentials more manifest than in the Echinonēidæ. No investigation that does not take into account stratigraphical and morphological features more delicate than suffice in some other groups can have much hope of success. It is with delight that I learn that my friend Dr. A. W. Rowe is following up his classic study of *Micraster* with a similar treatment of *Conulus*. In that way alone can the continuous or gently oscillating course of evolution of pelagic Echinoids be traced. But for the relatively littoral types, among which *Pyrina* must be classed, disjointed fragments of history are alone available; so that every detail needs accurate description, lest an inconspicuous feature that later proves a reliable guide should be overlooked. Thus, and thus only, may it be possible for some future worker to ascertain the distinctive characters of *Conulus* and *Pyrina*, which Lambert places in separate orders, while I cannot undertake to point out even generic differences that apply to all of the species therein included.

In respect of the two characters above indicated as possessing taxonomic value, it seems possible to find a rough distinction between *Conulus* and *Pyrina* in the following comparison. The interambulacral tubercles of *Conulus* are relatively small, with shallow areolæ, adapically; and larger, with deep areolæ, on the ambitus and adorally. Those of *Pyrina* are less distinctly differentiated, the tubercles of both surfaces being fairly large and the areolæ narrow but deep throughout. In both genera a chevron pattern is developed by the tubercles of each interambulacral plate, but in

Conulus there is a marked tendency for the downward (i.e. oral) sloping lines to consist of three tubercles in series (chiefly on the adapical surface), while in *Pyrina* they rarely comprise more than two. Thus the tuberculation of *Conulus* often appears somewhat irregular, while that of *Pyrina* consists of two regular transverse rows of tubercles on each plate. The ambulacral plates are grouped into triads almost throughout the areas in both genera, but the pore-pairs take on a triserial arrangement near the peristome in *Conulus*, and are practically uniserial in *Pyrina*. Because the form about to be described resembles *Pyrina* in tuberculation (though showing certain differences of detail) and *Conulus* in pore-disposition (though in an exaggerated manner), I have named it

CONULOPYRINA.

Holactypoida, Echinonæidæ (*sensu* Hawkins, 1920, non Lambert, 1918) ? Conulinæ.

Test oblong-oval; adapical surface tumid, apex central; adoral surface rounded, tumid posteriorly, peristome slightly invaginate; ambitus rounded. Peristome slightly elongate, about 0.18 of test-diameter. Periproct marginal, rounded adorally, sharply acuminate adapically. Apical system as in family. Ambulacra lanceolate, widening rapidly but evenly from apex to ambitus, slightly convergent adorally; plates apparently with Pyrinid triad grouping almost throughout. Pore-fields very narrow adapically, very faintly impressed; pore-pairs uniserial on adapical surface, definitely triserial from ambitus to peristome. Interambulacra about 2.5 times width of ambulacra on ambitus—each plate corresponds to about five ambulacral plates adapically, and about seven adorally. Primary tubercles arranged as in *Pyrina*; little additional ornament adorally, but greater parts of adapical surface occupied by crowded secondary tubercles and granules of various sizes, but with no scrobiculate arrangement.

Genotype.—*C. anomala* sp.n., ? Cenomanian, Shenley Hill. (Pl. VII.)

Description of the holotype (Sedgwick Museum, Walker Coll., "1905." "No. 3," Hawkins, *GEOL. MAG.*, Vol. LVIII, 1921, p. 58).

Measurements.—Antero-posterior diameter, 28.5 mm. = 1; transverse diameter, 27.0 mm. = 0.95; height, 14.5 mm. = 0.51; peristome (approximate diameter), 5.1 mm. = 0.18; periproct (long diameter), 8.0 mm.; periproct (transverse maximum diameter), 5.5 mm.; apical system (ant.-post. diameter), c. 2.3 mm.; ambulacra (width on ambitus), 4.7 mm. = 1. Interambulacra (width on ambitus), 12.0 mm. = 2.55.

Number of ambulacral plates (area IIIa), 103 (45 on adoral surface, 58 on adapical surface).

Number of interambulacral plates contiguous to above, 22 (10 adoral, 12 adapical).

Ambital outline ovoid, obtusely angular (Pl. VII, Figs. 1 and 2)

Transverse diameter greatest at ambulacra II and IV (which form blunt angles), thence lessening gradually to areas I and V (which are not at all prominent). A slight posterior elongation in area 5 is slashed by the marginal periproct. Adapical surface evenly convex, slightly flattened at apex. Ambitus rounded, ill-defined; there is no "posterior surface" (Pl. VII, Fig. 3). Adoral surface concave for the inner two-thirds; ambulacra hardly impressed, interambulacra very slightly tumid, except 5, which forms a marked protuberance below (i.e. oral to) the periproct (Pl. VII, Figs. 3 and 4).

Peristome not very clearly shown (? imperfect), slightly longer than broad, apparently oblique in the direction 3-I, but with an asymmetrical bay in II (? due to fracture). Invagination faint, being a continuation of the curvature of the adoral surface.

Periproct (Pl. VII, Fig. 3) large, strictly marginal, forming a marked indentation in the ambital outline, as seen from either surface. Rounded adorally, greatest width on ambitus, sharply acuminate adapically.

Apical system (Pl. VII, Fig. 5) small, approximately central, truncating the apex of the test. Four relatively large genital pores arranged in a trapezium with the posterior pair more widely separated (3 and 4 lie parallel to the antero-posterior axis, 1 and 2 make an angle therewith). Plates arranged as in *Pyrina* or *Comulus*, but contiguous posterior oculars subequal.

Ambulacra (Pl. VII, Fig. 7) similar, with simple pores throughout; I and V form a recognizable "bivium". Adradial sutures practically straight, sharply divergent adapically, subparallel on and above the ambitus, gently convergent adorally. Areas hardly inferior in width to interambulacra on peristome-margin. Plate-structure typically Pyrinid, wherever visible. Pore-fields very narrow adapically, with close-set, uniserial pore-pairs in faintly sunken peripodia; widening rapidly just below the ambitus, with strongly triserial pore-pairs (? without peripodia) over almost all the adoral surface. Pores uniformly minute. Major ornament in each column consisting of an external primordial row of tubercles continuous from peristome to apex (much reduced in size towards the ambitus); a second row (with very large tubercles adorally) extending from the fifth primordial tubercle to a point rather nearer the ambitus than the apex; and a third, internal, row (large below the ambitus) extending from the middle of the adoral surface to a point considerably above that reached by the second, with a few scattered members quite near the apex. Rows one and three are situated on the largest plates of the triad-groups, row two on the smaller primaries.

Interambulacra (Pl. VII, Fig. 7) slightly dissimilar, 2 and 3 being a very little less wide than 1 and 4; while 5 is distinctly narrower (though not carinate) and strongly inflated below the periproct. Plates remarkably even in height throughout, those around the ambitus being very slightly lower than the rest. Major ornament in

each column consisting of an almost median primordial row placed towards the adoral margins of the plates (except near the apex), continuous from apex to peristome, relatively small just below ambitus, and there accompanied by occasional orad supernumeraries. Radiad and interradiad rows introduced with some regularity (after about the third plate from peristome or apex), alternately near the apicad and orad margins of the plates, forming fairly regular transverse rows, the primordial tubercles entering the orad row of each plate. Five tubercles on each side of the median one is the rule for ambital plates, but occasionally more occur by development of three in place of the normal two in the oblique series.

Tuberculation (Pl. VII, Figs. 6 and 7), consisting of primary and secondary tubercles, and granules that sometimes appear almost tertiary tubercles. Primary tubercles with convex bosses and small perforate mamelons; areolæ always deep, but most noticeable adorally, where (from the ambitus) they become relatively large, occupying the greater part of the test-surface. Adapically the primary tubercles are comparatively small (much more so than in most species of *Conulus* or *Pyrina*) and rendered the less conspicuous by the strong development of secondaries. Secondary tubercles very numerous on adapical surface, with marked though shallow areolæ, giving a shagreen-effect above the level of the primaries. Scrobicular grouping around primaries not evident. Intervening space packed with granules (which may occasionally possess areolæ), adding to the extreme roughness of the adapical surface. No certain evidence of "sunken" or glassy tubercles, though in places impression of sand-grains gives suggestion of existence of the former.

The only specimen at present known was collected from the "Limestone Lenticles" at Shenley Hill, near Leighton Buzzard, Bedfordshire. The horizon of these lenticles is a matter of controversy, but the palæontological evidence points fairly conclusively to their Cenomanian age—perhaps correlating them with the sub-zone of *Catopygus columbarius* at the base of the zone of *Schlenbachia varians*. (The alternative reading of the section would locate the horizon in or about the Lower Gault.)

Discussion of Affinities.

In the preliminary note (GEOL. MAG., Vol. LVIII, 1921, p. 58) I drew attention to the marked resemblance of the specimen to an *Holcotypus* with marginal periproct, mentioning the Lower Oolitic species *H. hemisphaericus* in particular. The appropriateness of this comparison will be obvious to anyone who handles the specimen; but there are few features of real importance in which it is worth emphasizing. In essentials *C. anomala* is emphatically *not* one of the *Holcotypidæ*, for it has no fifth genital, and its interradiad tuberculation is double on each side of the median row; whereas in *Holcotypus* there is always a fifth genital, perforate in Cretaceous types (*Coenholcotypus*), and the interradiad tubercle-series form single transverse

lines on each plate. But the extreme smallness of the primary tubercles of the adapical surface, and the wealth of simple secondary tuberculation and granulation there, coupled with the rapid increase in size of the primaries at and orad to the ambitus, are of such a quality that *Holactypus* rather than *Conulus* (still more than *Pyrina*) affords the nearest comparison. But such a character (indicative of difference in size of the radioles on the two surfaces) is more likely to be adaptive than intrinsic, and so can hardly be invoked as involving close affinity. Again, the shape, size, and position of the periproct are all comparable with those features in *Holactypus*.

The points of chief importance wherein *Conulopyrina* differs from all other Echinonēidæ (*sensu meo*) are: the prolongation of triserial arrangement of the podial pores over the entire adoral extent of the ambulacra, the position of the periproct (roughly intermediate between *Conulus* and *Pyrina*), and the quality and pattern of the surface ornament of both areas. *Pileus* is the only Holactypoid in which the pore-pairs show comparable departure from the uniserial plan (both in quality and extent), but there is no other apparent reason for suggesting any close relationship between the two genera. The position of the periproct is certainly suggestive of a stage midway between *Pyrina* and *Conulus*, but the known migration of this aperture in ontogeny makes it unsafe to give *Conulopyrina* such a phyletic place, since only one example is available. It is, however, far from impossible that this may be its true interpretation.

The order of appearance and disappearance of the main tubercle-rows on the ambulacra is very strange. That the primordial continuous row should be external (adradial) is normal for the order, although the reduction of its members to almost secondary rank on the adoral surface is unusual. The situation of the second row on the alternate primaries is normal, but the disappearance of this series adapically while the third row still persists is quite anomalous.

The arrangement of the interr radial primary tubercles is fairly typical of that found in *Anorthopygus* or *Pyrina*, but there are more unituberculate plates than is usual in the Echinonēidæ. However, the extraordinary congestion of the minor ornament on the adapical surface, coupled with the great reduction in size of the primaries in that region, seem unique for the Holactypoida, and can best be compared with the granulation of such Caratomids as *Conulopsis* ("*Echinoconus*" of Lambert). This comparison is emphasized by the maintenance of sunken areolæ in the reduced apical tubercles; but I should hesitate to suggest any phyletic meaning in the character, especially in view of the great contrast in ambulacral structure between *Conulopyrina* and *Caratomus*.

To sum up, *Conulopyrina* is definitely a member of the Echinonēidæ (as I interpret the family). It is neither a *Conulus* nor a *Pyrina*; it possesses some of the characters of both these groups, and others present in neither. Its resemblance to *Holactypus* is most probably

a case of "heterogenetic homœomorphy", perhaps induced by similarity of habitat. On the evidence at present known, I am inclined to consider it as representing either the common stock from which both *Pyrina* and *Conulus* arose (though not by any means the actual radicle itself), or else as an offshoot from the *Pyrina* stock parallel to the *Conulus* line, but overreaching the *Conulus* stage.

EXPLANATION OF PLATE VII.

- Fig. 1.—*Conulopyrina anomala*. Adapical view. Natural size. All ornament omitted in this and three following figures.
 Fig. 2.—*Conulopyrina anomala*. Adoral view. Natural size. The actual peristome margin is obscure in the original; see text.
 Fig. 3.—*Conulopyrina anomala*. Posterior view. Natural size.
 Fig. 4.—*Conulopyrina anomala*. Side view. Natural size. The broken line near the bottom of the figure represents the peristomal concavity of the adoral surface.
 Fig. 5.—*Conulopyrina anomala*. Apical system enlarged.
 Fig. 6.—*Conulopyrina anomala*. Detail of parts of the adapical surface midway between apex and ambitus, taken in a place where the sutures of the ambulacra are visible.
 Fig. 7.—*Conulopyrina anomala*. Area III and contiguous interambulacral columns. Only primary tubercles shown. Ambulacral plating not inserted, but occasionally determinable as "Pyrinid" on both adoral and adapical surfaces. The broken curve across the figure is the line of the ambitus.

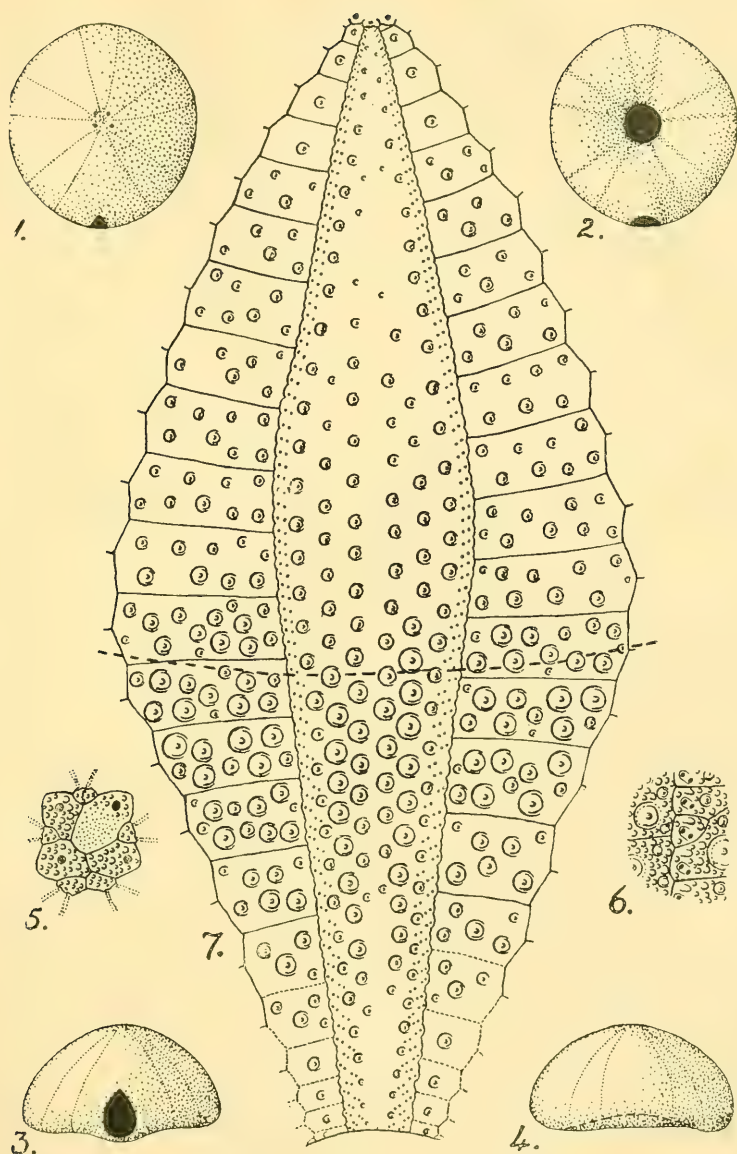
Ammonites from the Upper Lias, Railway-cutting, Bloxham, Oxon.

By L. RICHARDSON

IMMEDIATELY east of Bloxham Station is a cutting through the Marlstone and basement beds of the Upper Lias. The Liassic deposits are now for the most part hidden by vegetation, but when the line was made and for some years subsequently large numbers of fossils—principally ammonites—were collected from them. Several geologists have published particulars concerning the section.¹ The writer has in his collection a number of ammonites from here, which have been examined by Dr. A. E. Trueman. The object of this communication is to place on record the result of his examination.

First, however, some particulars—mainly derived from accounts published by previous authors—may be given. The cutting is through the Marlstone and basement beds of the Upper Lias. At one place the beds are faulted, and about 3 feet of the "Sandy Beds" of the Middle Lias were exposed beneath the Marlstone. The Marlstone is about 24 feet thick. No traces have been observed here of

¹ T. Beesley, *Proc. Geol. Assoc.*, vol. v (1877), p. 168; T. Wright, "Monograph of the Lias Ammonites of the British Islands," *Palæont. Soc.*, pt. iii (1880), p. 128; E. A. Walford, *Quart. Journ. Geol. Soc.*, vol. xxxix (1883), p. 229; *Proc. Geol. Assoc.*, vol. xiv (1895), p. 177, "The Lias Ironstone of North Oxfordshire," Banbury and London (1899), p. 14; H. B. Woodward, "The Jurassic Rocks of Britain, vol. iii—The Lias of England and Wales (Yorkshire excepted)," *Mem. Geol. Surv.* (1893), p. 269.



H. L. H. del.

CONULOPYRINA ANOMALA, gen. et sp. nov.

[To face p. 426.

the Transition Bed (*acuti* hemera), Paper Shales (*tenuicostati* hemera), or Fish Bed (*exarati* hemera). A thin bed of Upper Lias limestone, of *falciferi* hemera, immediately succeeds the Marlstone and may be best described as "welded on" to it. This limestone is succeeded—according to H. B. Woodward¹—by

"Blue and grey marly clay with thin bands of grey ferruginous nodular earthy limestone. *Ammonites communis*, *A. bifrons*, *A. serpentinus*, etc."

Above comes the Cephalopoda Bed of certain local authors. This bed is 5 inches thick, and in places is a ferruginous oolitic limestone. It has yielded *Frechiella* aff. *subcarinata* (Young & Bird), and is of *subcarinati* hemera. Resting on the last bed and occupying hollows in its surface is a thin layer, barely half an inch thick, made up entirely of crinoidal remains. Of this layer Mr. E. A. Walford has written:—

"Thin and inconspicuous as the crinoidal stone is, I have traced it over the country ten miles north of Banbury, where below it are seen the Fish Bed and the Transition Bed. . ."²

Clays, measuring some 15 feet, complete the section. They are of *fibulati* date. The total thickness of the Upper Lias in this neighbourhood is about 70 feet. The deposit above the "crinoidal stone" is probably clay only, and the whole of *fibulati* date. Unfortunately, there are not any exposures of use in the vicinity.

As the result of his examination of the ammonites, Dr. Trueman reports:—

"It has not usually been possible to assign specific names—several new species are no doubt included. The specimens are in many cases identical with those I have from Grantham and undoubtedly they indicate the presence of beds similar to those that are so fossiliferous there.

Judging from my experience there, I should say that the *Falciferum*-? *Pseudovatum*- and *Subcarinata*-Zones are represented, with quite possibly the *Fibulatum*-Zone (judging from the *Pseudolioceras*)."

The following is the list of the ammonites:—

Caloceras aff. *fonticulum* (Simpson).

„ sp.

Dactylioceras cf. *acanthus* (d'Orbigny).

„ *commune* (J. Sowerby).

„ cf. *commune* (J. Sow.).

„ cf. *commune* (J. Sow.). Stout form.

„ cf. *gracile* (Simpson).

„ aff. *semicelatum* (Simpson).

„ sp. Intermediate between *Peronoceras holandrei* (d'Orb) and *D. commune* (J. Sow.).

Frechiella aff. *subcarinata* (Young & Bird). A little more slender than the type.

Harpoceras connectens (Haug.).

„ aff. *falciferum* (J. Sow.)

¹ "The Jurassic Rocks of Britain, vol. iii—The Lias of England and Wales (Yorkshire excepted)," *Mem. Geol. Surv.* (1893), p. 269.

² *Proc. Geol. Assoc.*, vol. xiv (1895), p. 178.

428 *Ammonites from the Upper Lias, Bloxham, Oxon.*

Hildoceras walcotti (J. Sow.). Common.

„ *aff. walcotti* (J. Sow.). Common.

„ *cf. hildense* (Young & Bird). Fairly typical, but
furrow too deep for type.

Harpoceratoides sp. Identical with a form in the *Falciferum*-
and *Pseudovatum*-Zones at Grantham.

? *Peronoceras* sp.

Pseudolioceras *cf. boulbiense* (Y. & B.).

„ *cf. multifoliatum* (Simpson).

Thysanoceras *aff. cornucopia* (Y. & B.). Smooth form.

REVIEWS.

PREHISTORY : A STUDY OF EARLY CULTURES IN EUROPE AND THE MEDITERRANEAN BASIN. By M. C. BURKITT, M.A., F.G.S. With a short preface by L'Abbé H. BREUIL. pp. i-xx, 1-438, and 47 plates. Cambridge University Press, 1921. Price 35s.

FOR a long time the view that man appeared after the Glacial period, at any rate in Europe, was unhesitatingly accepted, but of recent years this view has been challenged, though we have as yet no unanimity of opinion as to the definite relationship of the various civilizations to the Glacial period.

As the result of recent research we must readjust our ideas, and new books necessarily arise. Prominent among them in this country is Sollas' scholarly work *Ancient Hunters* and W. B. Wright's stimulating treatise on the *Quaternary Ice Age*, and now Mr. Burkitt has written a book which "must be regarded as an attempt to give a general idea of the subject" of prehistory, the greater part of which is devoted to the Palæolithic period.

Though the whole of the book is of interest to geologists, they will naturally turn at first to Chapters II and III, dealing with "Geological Conditions" and "Man in Relation to Geology". In Chapter II the author divides the whole history of the world into an introduction succeeded by five volumes, of which the recent period represents volume v. It would have been well if he had warned the general reader that the volumes are far from being of equal importance as regards lapse of time. He next gives an account of the classification of the Pliocene and Pleistocene accumulations. The origin of the Ice Age is dealt with at some length. This seems hardly necessary when we consider our real ignorance of the causes of secular changes of climate and the space thus occupied might well be devoted in a later edition to a fuller discussion of geological matters bearing more directly on the subject. In Chapter III the author boldly sets forth to trace the relations between the various archæological divisions and those put forward by geologists. He is obviously strongly influenced by researches of foreign writers in districts which he has himself visited, and, indeed, it is most necessary to take account of these. The correlations favoured by Mr. Burkitt may well be correct, but as they are in opposition to the views of a number of geologists who have made detailed studies of our British Pleistocene and Holocene deposits, it would be well to take some notice of these views, even though they frequently conflict with one another; furthermore, it might have been mentioned that hitherto no instance has been recorded in Britain of any undoubted Lower Palæolithic implement extracted from a deposit overlain by indisputable boulder-clay, though some artefacts found by Reid Moir below boulder-clay at Ipswich may even be proto-Mousterian. In future the author will probably speak with less uncertain note of artefacts from the Red Crag.

A chapter on flint-fracture and palæolithic tools contains an account of the principal kinds of tools and reference to the characteristic tools of different periods, which are more fully considered in succeeding chapters, which treat of these periods in greater detail. Plates I – V give illustrations of various implements and the reader would no doubt wish to have more frequent reference to these plates in the text.

Chapter XIV is entitled “Prehistoric Man”, and the author gives only “a short general epitome of the various prehistoric races, without much special reference to the physical differences in their anatomy”. This is a difficult task, and the chapter suffers from undue condensation.

The latter part of the work, from page 192 onwards, is devoted to prehistoric art. Here the author is at his best. He has himself seen most of what he describes, and the reader will follow this portion with keen interest.

Mr. Burkitt must be warmly congratulated on this book. It will be read with pleasure and profit, and is a storehouse of information for purposes of reference. It has been suggested above that at times he goes further than our present knowledge warrants, but one recognizes in this the sign of his intense enthusiasm. No doubt alterations will be made in later editions as the result of future work, and at the same time several little slips which have escaped notice during proof-reading will be altered. That future editions will be called for seems certain, for the book is a worthy addition to the literature of the science.

J. E. M.

A MANUAL OF SEISMOLOGY. By CHARLES DAVISON. pp. xiii + 256.
Cambridge University Press, 1921. Price 21s.

THE study of earthquakes has always been regarded as essentially a branch of geology: it is a subject on which the impress of English workers is predominant, yet since the appearance of the last edition of the late John Milne's brilliant, though almost unarranged, handbooks, now a full generation ago, there has been no satisfactory manual of the study of earthquakes in the English language. Modern seismology has run principally to the study of the long-distance records of great earthquakes, a subject which is interesting, but has little or no geological application. Dr. Davison's manual, being one of a professedly geological series, devotes but a small section to this modern development of the older seismology, and is almost wholly devoted to the earthquake proper, which can be felt and causes visible damage. To the study of this branch of geology it will serve as a useful introduction, covering the ground in a satisfactory manner, and at the same time giving ample indication of the works which need to be studied by those who wish to go deeper into the subject. It might, perhaps, be thought that an undue amount of space is devoted to small and feeble earthquakes,

but these are vastly more numerous and, when the study of them is more complete, may prove to have as great geological importance and interest as the more sensational, and, at present, more fully studied, destructive shocks. We regret the omission of reference to Col. Harboe's speculations on the nature of earthquake origins, as his studies seem to open up a line of research which is likely to lead to important results; and we notice that Dr. Davison, like almost every other writer, has failed to detect the logical flaw in Dutton's method of determining the depth of origin, which results from the two-fold meaning attached to the word intensity, used in the formulæ as a measure of the amount of energy transmitted over a unit of area in a unit of time, and in the application as synonymous with the acceleration of wave-particle. These are the only omissions of importance which we have noticed in a well-written, well-balanced, and adequate manual of a subject for which such an introduction was wanting and much needed.

THE MINERAL INDUSTRY OF THE BRITISH EMPIRE. Imperial Mineral Resources Bureau Handbooks: Manganese, pp. 151, 3s. 6d.; Tungsten, pp. 44, 1s.; Coal, Coke, and By-Products, pp. 124, 3s. 6d.

THESE pamphlets continue the plan of the preceding issues. Besides the necessary statistics the monographs on manganese and tungsten contain useful accounts of the geology and mineralogy of the deposits, with excellent bibliographies in each case. The volume on coal and its products deals mainly with statistics and the properties of different coals as fuel, and there is little to interest a geologist.

THE IRON AND ASSOCIATED INDUSTRIES OF LORRAINE, THE SARRE DISTRICT, LUXEMBURG, AND BELGIUM. By A. H. BROOKS and M. F. LA CROIX. Bull. 703, U.S.G.S., pp. 131, with 2 plates and 12 text-figures. 1920.

THIS bulletin is mainly metallurgical, statistical, and political, but it includes a clear though brief account of the geology of the iron fields, which should be of value to those interested in the subject. There is a good bibliography, and a most useful feature is a large-scale folding map showing the geographical position of the iron and coal fields and their relation to the great industrial districts of Western Europe. The latest estimates show that France has now control of 48 per cent of the European iron-ore reserves, and for many years to come the Lorraine iron field must continue to be a dominant factor in European politics. Few people realize that the Jurassic system was the chief cause of the Great War.

SPECIAL REPORTS ON THE MINERAL RESOURCES OF GREAT BRITAIN,
Vol. XVIII: ROCK-SALT AND BRINE. By R. L. SHERLOCK.
Mem. Geol. Survey, pp. vi + 123, with 2 plates and 16 text-figures. 1921. Price 5s. net.

HITHERTO it has been very difficult to obtain any information as to the salt deposits of Great Britain, and especially those not in Cheshire, but this difficulty is now removed. Out of the materials at his disposal Dr. Sherlock has constructed an extremely interesting memoir, well-written and well-arranged, and conveying just the kind of information most useful to geologists, economic or otherwise. Few people know much about British salt outside of Cheshire, and hardly anyone could give even a vague description of the salt-fields of Lancashire, the Isle of Man, and Somerset, which are mainly recent discoveries; as to the horizon of the Middlesbrough salt deposits there still seems to be room for some doubt. Some very interesting facts are recorded as to the discovery of salt-beds in the borings at Market Weighton and at Barlow, near Selby. In both these cases the salt is in the Upper or Middle Permian. The bed is 20 feet thick, and Barlow seems to be near its western limit, but nothing is known as to its possible eastward extension.

WISSENSCHAFTLICHE FORSCHUNGSBERICHTE, BAND II: ALLGEMEINE
GEOLOGIE AND STRATIGRAPHIE. By Dr. A. BORN. pp. 145.
Steinkopff, Dresden and Leipzig, 1921. Price 5s. 7d.

IN a general introduction to this series the editor, Dr. R. E. Liesegang, remarks that five years have been torn out of the lives of most men of science by the war. These small books are an attempt to supply for each subject a bibliography of what has appeared during the years 1914-18, together with, in the case of many subdivisions, brief summaries and criticisms of the contents of the more notable publications. We cannot help pointing out, however, that this geological volume is of a very one-sided character. Nearly all the references are to German, Austrian, and Swiss publications, with a few American ones; in a fairly lengthy search we have discovered one quotation of a paper in the GEOLOGICAL MAGAZINE, one French and one Italian paper. But as a record of what has been done in German and Austrian geology during the war years the book will be most useful.

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- TEALL (J. J. HARRIS), M.A., F.G.S. *British Petrography: with special reference to the Igneous Rocks.* With 47 plates. Royal 8vo. Cloth. £3 3s. net.
- VAN DEN BROECK (E.), MARTEL (E. A.), AND RAHIR (EDM.). *Les Cavernes et les Rivières souterraines de la Belgique.* Bruxelles, 1910. 2 vols. 8vo. With 26 plates and text illustrations. £1 10s.

JUST PUBLISHED.

Catalogue of the Fossil Bryozoa (Polyzoa) in the Department of Geology, British Museum (Natural History). *The Cretaceous Bryozoa* (Polyzoa). Volume III. The Cribrimorphs, Part I, by W. D. LANG, Sc.D. pp. 269, 8 plates, and 115 text-figures. With general index, index to systematic names of Polyzoa and explanation of Plates. 8vo. Cloth. £1 10s.

The Jurassic Bryozoa, by J. W. GREGORY, D.Sc. pp. [viii] 239, 22 woodcuts, and 11 plates. 8vo. Cloth. 1896. 10s.

The Cretaceous Bryozoa, by J. W. GREGORY, D.Sc. Vol. i, pp. xiv, 457, 64 woodcuts, and 17 plates. 8vo. Cloth. 1899. 16s.

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OCTOBER, 1921.

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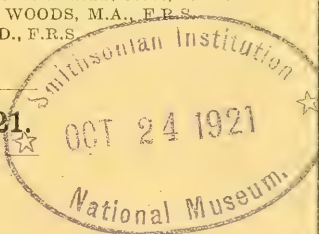
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THE
GEOLOGICAL MAGAZINE

VOLUME LVIII.

No. X.—OCTOBER, 1921.

EDITORIAL NOTES.

WE regret to have to record that our colleague, Dr. Henry Woodward, died at his home at Bushey, Herts, on 6th September, in his 89th year. He retained his active interest in our work almost until the end, and passed away peacefully in the presence of his family.

In association with the late Professor T. Rupert Jones, Dr. Woodward founded the GEOLOGICAL MAGAZINE in July, 1864, and from July, 1865, to December, 1918, he edited every number except one, which he entrusted to his nephew, the late Horace B. Woodward, when he felt overcome by the loss of his younger son in 1901. His task was, indeed, more than that of editing, for he was faced with the usual difficulty of technical periodicals—a circulation too restricted for financial success. At intervals he had to enlist the sympathy and help of generous friends, whom he found always ready to second his disinterested efforts to promote geological science by maintaining a regular serial publication.

It has been well said that since 1864 every British recruit to geology has begun his career as an author in the pages of the GEOLOGICAL MAGAZINE. Dr. Woodward's genial personality and note of encouragement were always stimulating to beginners, and even when he considered drastic editing necessary, his tactful ways usually smoothed all difficulties. His wise advice on the presentation of a subject often turned unacceptable efforts into valuable contributions, and his judicious treatment of over-eager correspondents not infrequently softened acrimonious controversies into reasonable discussions. His hospitable reception of many papers which had been refused elsewhere was by no means the least of the services he rendered to geological science as editor. He was, indeed, an impartial critic of every genuine effort to advance.

A full biography of Dr. Woodward will appear in a later number.

At the first meeting of the Advisory Committee for the Metalliferous Mining Industry the Secretary for Mines, Mr. W. C. Bridgeman, M.P., welcomed the members in an opening speech. After deploring the depressed state of the mining industry, he went on to state, in emphatic terms, that the Government could in no circumstances afford any financial assistance. One must suppose that the industry as a whole does not command enough votes to be of any importance for electoral purposes. It would be a matter of much interest to compare the amounts of public money spent on coal mining and metalliferous mining respectively. With one portion of the speech we are in hearty agreement: "he thought that the mining industry in this country had suffered in the past from an insufficient acquaintance with geological information in regard to all its metals." This is certainly true, but of late a good deal has been done to remedy this defect, especially by the publication of the valuable series of Special Reports of the Geological Survey on the Mineral Resources of Great Britain. We are glad to note that the Secretary for Mines went on to state that arrangements had been made for co-operation between his department and the Geological Survey in this matter. From this much good should arise.

* * * * *

PROFESSOR W. G. FEARNSIDES, of Sheffield University, has gone to Canada and the United States on a year's leave in order to study geological conditions in those countries. In his absence the geological department at Sheffield will be in charge of Mr. W. H. Wilcockson, Lecturer in Geology.

* * * * *

DR. ARTHUR HOLMES, formerly Assistant Demonstrator in Geology at the Imperial College of Science and Technology, has lately returned to Burma, after a trip home on leave. He will in future reside at Yenangyaung in order to manage the oil and coal fields of the Yomah Oil Company. We understand that Dr. L. Dudley Stamp will shortly proceed to Burma to undertake geological work under the same company.

* * * * *

DR. STANLEY SMITH recently sailed for Canada to take up the duties of Assistant Professor of Geology at Queen's University, Kingston, Ontario.

* * * * *

THE 89th meeting of the British Association for the Advancement of Science, held at Edinburgh from 7th to 13th September, did not present any features of outstanding interest to geologists. The President of the Association, Sir T. E. Thorpe, devoted part of his inaugural address to an account of the organization and work of the Council of Scientific and Industrial Research, the latest body to assume control of the Geological Survey. On another page we give a list of the papers read in Section C (Geology). Besides these papers

there were joint discussions with other sections on the Mid-Scotland Canal, the Oldest Land Flora, and that well-worn subject, the Age of the Earth. We are not aware that any new geological evidence has recently come to light bearing on this question, which has been abundantly discussed in recent years by Professor Sollas and others.

* * * * *

DR. J. S. FLETT, F.R.S., President of Section C, devoted his address to the fascinating subject of Experimental Geology, with special reference to the work of Sir James Hall of Dunglass, and its bearing on modern research. We greatly regret that we are unable to afford space to reprint this address in full in the Magazine. It should be read by all petrologists, to whom it will afford much food for thought. We feel sure that few geologists of the present day are acquainted with the wonderful work carried out by Hall a century ago in the investigation of the behaviour of rocks and minerals at high temperatures, and we must be grateful to Dr. Flett for his appreciative sketch of this great Scotsman and great geologist.

* * * * *

THE excursion of the Geologists' Association to Belgium from 20th August to 3rd September was attended with much success. The general direction of the excursion was in the competent hands of Dr. L. Dudley Stamp, and the domestic arrangements were excellently and efficiently managed by Miss M. S. Johnston, Mr. R. S. Herries, and Mr. W. Wright. Consequently everything went off without a hitch, in spite of the difficulty of securing accommodation for a party of nearly fifty in remote places. The following gentlemen most kindly conducted excursions to the localities which they have made their special study: M. A. Renier, M. F. Halet, and Dr. E. Asselberghs, of the Geological Survey of Belgium; Professor J. Cornet, of the School of Mines, Mons; M. Eug. Mailleux, of the Musée Royale d'Histoire Naturelle, Brussels; the Abbé G. Delépine of the Catholic University of Lille, Dr. P. Pruvost, and M. Kaisin. The party stayed at Brussels, Mons, Nismes (for the Couvin district), and Namur, and visited numerous sections in the Devonian, Carboniferous, Cretaceous, and Tertiary rocks, as well as obtaining a glimpse of the Silurians of the Brabant massif and inspecting the vast porphyry quarries at Quenast, the source of so much of the horrible *pavé* of Belgian roads. Professor Dollo also kindly showed the party over the geological department of the Musée Royale at Brussels, and gave a most interesting description of the wonderful collection of reptilian remains, while on the same occasion M. Rutot explained the collection of flint implements. The organizers of this excursion are to be heartily congratulated on the success that attended their labours, which must have been of the most arduous nature.

ORIGINAL ARTICLES.

Silica Percentages of Igneous Rocks.

By V. A. EYLES, B.Sc., and J. B. SIMPSON, B.Sc. (Agri), B.Sc.

INTRODUCTION.

FIGS. I-VII give a graphic representation of the average silica percentage of a number of igneous rock types, so arranged as to show the relation between silica-percentage and rock-nomenclature. All the analyses used were obtained from the 1917 edition of H. S. Washington's *Chemical Analyses of Igneous Rocks*.¹ This book contains some 8,000 rock analyses from many parts of the world. They are divided into two classes, superior and inferior. Only those of the former category (some 6,000 in all) have been utilized.

We should at the outset like to make ourselves clear on two points :

(1) The scope of our paper is limited by the acknowledged fact that the nomenclature of igneous rocks depends on many factors in addition to silica percentage.

(2) Our graphs are intended to show what has actually been the practice in the past, rather than to supply a definite ruling for the future.

We hope, however, that in view of the general habit of classifying igneous rocks broadly into three groups—acid, intermediate, and basic—our results may have general interest and suggestiveness.

CONSTRUCTION OF CURVES.

The method of construction of the curves may best be explained by reference to a typical example, such as that for basalt (Figs. Ia, Ib). Consider first Fig. Ia. One finds there a record of the fact that while $8\frac{1}{2}$ per cent of analysed basalts have 46 per cent of silica (reckoned to the nearest whole number), $9\frac{1}{3}$ per cent of them have 47 per cent of silica, and so on. It was found that the available evidence plotted in this fashion gives somewhat inconveniently uneven curves. Accordingly "smooth curves" have been derived by calculating mean points at the chief irregularities in the rough curves. Thus groups of points A, B, C, in Fig. Ia become points A¹, B¹, C¹ in Fig. Ib. In addition to this, low-lying flat parts of curves, such as that which occurs under D in Fig. Ia, have been eliminated, since they obviously lie outside the extreme limits of the species considered.

The following table explains exactly the data used in constructing each curve, stating, for instance, the number of analyses employed. Hypabyssal rocks, with the exception of dolerites, have not been treated, owing to the present relatively undeveloped state of their classification and nomenclature.

¹ Prof. Paper 99, U.S. Geol. Survey.

LAVAS

Fig. Ia.

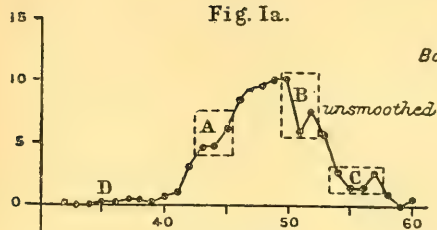


Fig. Ib

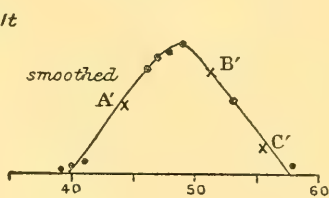


Fig. II.

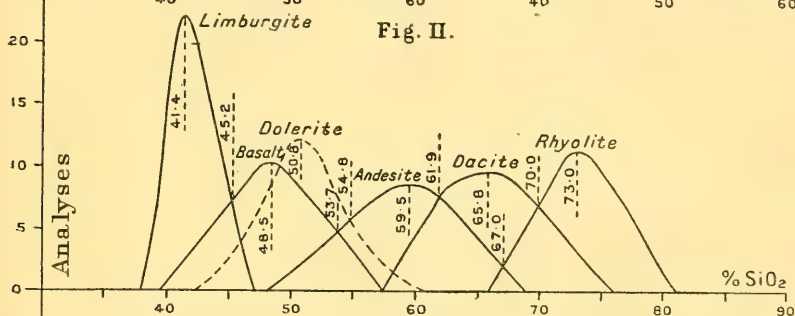


Fig. III.

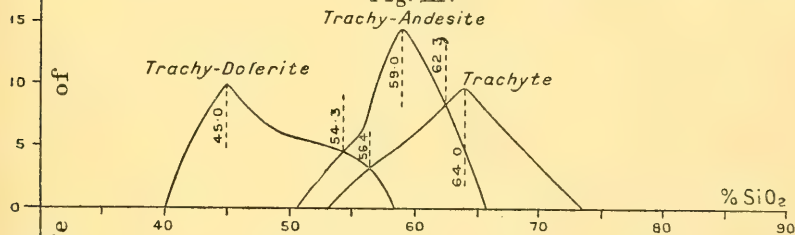
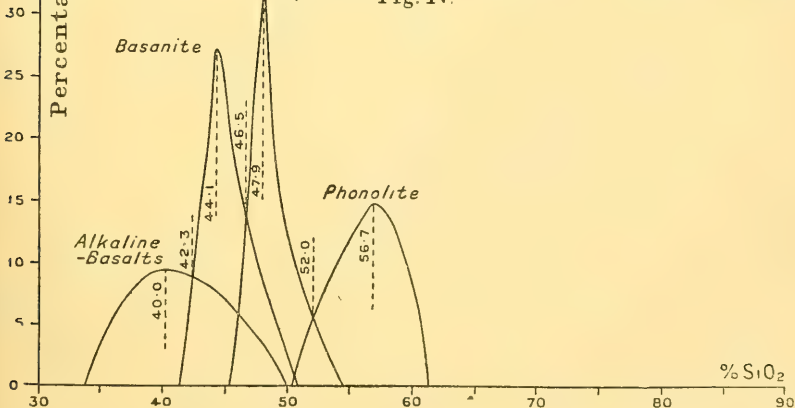


Fig. IV.



PLUTONIC ROCKS

Fig. V.

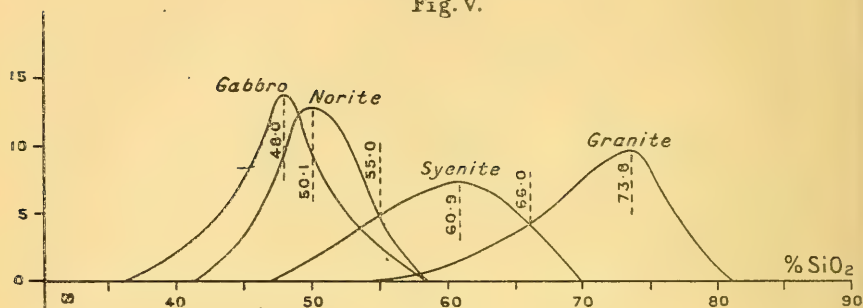


Fig. VI.

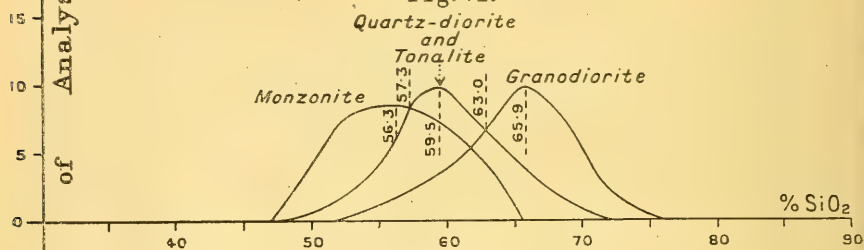


Fig. VII.

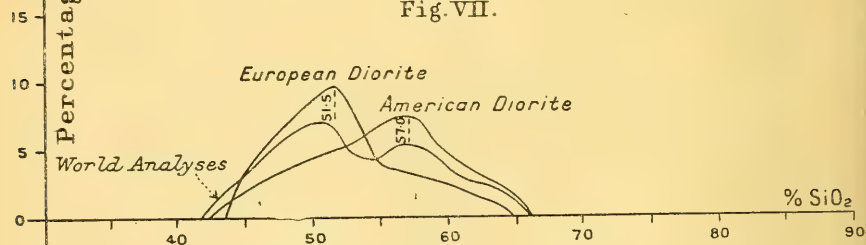
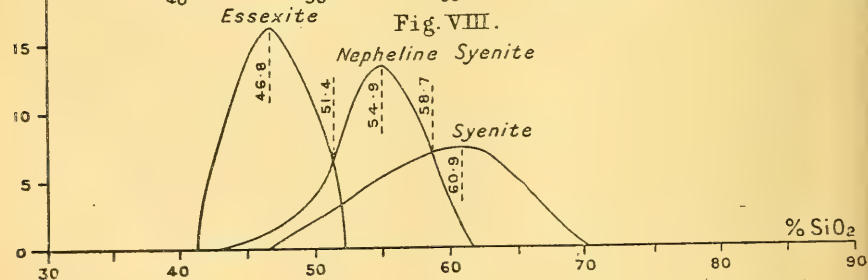


Fig. VIII.



TABULAR STATEMENT ACCOMPANYING FIGS. I-VII.

Rock Name.	No. of analyses.	Arithmetic mean SiO ₂ %	SiO ₂ % at curve apex.	Remarks.
Limburgite . . .	41	42.2	41.4	<i>Includes</i> : Basalts ; Olivine-, Quartz-, and Orthoclase - Basalts ; Olivine-free Basalts, Basaltic Glass, Scoria, Palagonite and Tachylyte. <i>Excludes</i> : "Alkaline" Basalts (see below); Hornblende and Mica-Basalts; Labradorites, Variolites, and Andesite-Basalts.
Basalt . . .	453	48.4	48.5	
Dolerite . . .	163	51.3	50.8	<i>Includes</i> : Diabase and Dolerite. <i>Excludes</i> : Altered Diabase.
Andesite . . .	455	59.5	59.5	<i>Includes</i> : Rhyolites, Liparites, and a few Acid Pantellerites.
Dacite . . .	131	65.5	65.8	
Rhyolite . . .	275	72.6	73.0	
Trachydolerite	50	48.4	45.0	
Trachyandesite	27	59.1	59.0	<i>Includes</i> : Trachytes ; Quartz-, Soda-, Calcite-Trachytes ; Trachytic Pumice, Bombs, Obsidian, and Pitchstone.
Trachyte . . .	163	62.5	64.0	
"Alkaline" Basalt	100	40.9	40.0	<i>Includes</i> : Hauyne-, Nosean-, Leucite-, Nepheline-, Analcite-, Melilitite-Basalts. <i>Excludes</i> : Tephrites ; Basanites ; Nephelinite ; Leucite ; Hauynophyre ; Cecilitite.
Basanite . . .	29	45.4	44.1	<i>Includes</i> : Gabbros ; Quartz-, Orthoclase-, Micro-, and Essexitic-Gabbros. <i>Excludes</i> : Gabbro-Norite, Diorite-Gabbro; Gabbro-Diorite, Enstatite-, Bronzite-, and Hypersthene-Gabbros.
Tephrite . . .	47	48.3	47.9	
Phonolite . . .	88	56.5	56.7	
Gabbro . . .	202	48.6	48.0	
Norite . . .	65	50.1	50.1	<i>Includes</i> : Norites ; Gabbro-Norites ; Enstatite-, Bronzite-, and Hypersthene-Gabbros.
Syenite . . .	98	58.6	60.9	<i>Excludes</i> : Nepheline-Syenites.
Granite . . .	643	71.2	73.8	<i>Includes</i> : Granites ; Granitites ; Adamellites ; Microgranites ; Granophyres ; Graphitic Granites ; Rapakivi Granites ; Alaskite-Granites ; Paisanites ; Charnockites. <i>Excludes</i> : Granodiorites.
All Diorites . .	142	52.9	—	<i>Excludes</i> : Quartz-Diorite ; Tonalite ; Gabbro-Diorite ; Diorite-Gabbro.
"European" Diorites	53	—	51.5	
"American" do.	83	—	57.0	<i>Excludes</i> : Essexite-Gabbros, -Dolerites, -Lavas, -Diabases, and -Porphyrites ; Diorite-Essexites.
Monzonite . . .	50	56.3	56.3	
Quartz-Diorite and Tonalite	98	60.3	59.5	
Grano-Diorite .	52	64.5	65.9	
Essexite . . .	44	47.1	46.8	<i>Includes</i> : Foyaite ; Litchfieldite ; Ditroite ; Laurdalite ; Sodalite- ; and Leucite-Syenite.
Nepheline Syenite	116	56.2	54.9	

The number of analyses taken for each individual type is, we believe, in most cases larger than has hitherto been used in discussions of this nature. It will be seen that the value given by the apex of each curve varies slightly from the average silica percentage. We suggest the former value as more appropriate, since rocks obviously wrongly named have been eliminated in making the smooth curves.

DISCUSSION OF THE CURVES.

A few points of interest are evident in the graphs.

The considerable lateral range of a curve may indicate either looseness in naming, or lack of definition as regards silica-percentage.

The absence of sharp demarcation between types, which we find in nature, is well brought out. The overlapping of the curves is largely due to the influence of those factors, other than silica-percentage, which enter into the present system of classification. The relative basicity of the felspathoid branch of the igneous rocks is well shown.

The diorite curve, plotted on the basis of all recorded analyses, has two well-marked apices, the one at 51, the other at 57. As this feature is too pronounced to be smoothed over, a closer examination of the data has been made. It is found, on considering separately such analyses of diorites as are recorded in European and American publications respectively, that these give two totally distinct curves (Fig. VII). It will be seen that the "European" curve is much the more basic of the two. In fact, in Europe, diorite, as opposed to quartz-diorite, generally means a basic, rather than an intermediate, rock. This is all the more remarkable since rocks named diorite-gabbros and gabbro-diorites have been excluded in the drawing of the curves. Even taking all the diorites together it is clear that their mean silica-percentage is markedly lower than what is usually given as typical for a diorite analysis.

It is not our intention to dogmatize on the curves, however, but to make them available to those who may be interested in particular points.

In conclusion we would like to thank our colleague, Mr. E. B. Bailey, for his help and advice in this compilation.

The Wackerfield Dyke, County Durham.

By ARTHUR HOLMES, A.R.C.S., D.Sc., F.G.S., & STANLEY SMITH, M.A., D.Sc., F.G.S.

(With analysis by H. F. Harwood, M.Sc., Ph.D.)

(PLATE VIII.)

THE dyke to be described in this paper has not hitherto been noticed in petrological literature, although the western part has been recorded on the map of the area by the Geological Survey. It exhibits, nevertheless, some interesting features and adds data to our knowledge of the minor intrusions of north-east England.

The field investigation has been carried out by one of us [S.S.] and the petrological study by the other [A.H.], and a very complete analysis of the rock has been contributed by Dr. H. F. Harwood.

Field Relations : Situation : 1 inch Geological Map 102 S.W. (New Series Sheet 32), 6 inch map Durham Quarter Sheets 47 N.E. and 48 N.W. Latitude (approx.) $54^{\circ} 36'$; longitude $1^{\circ} 45' - 1^{\circ} 46'$.

The dyke runs E.N.E.—W.S.W. and can be followed for 1,700 yards, from an old quarry a quarter of a mile north-east of Wackerfield (a hamlet 2 miles north-east of Staindrop) to the edge of Trunnelmire Plantation. It outcrops on the divide between the Tees and the Gaunless, a tributary of the Wear, and itself forms the axis of a ridge.

Description of Outcrop.—The dyke has been exposed by quarrying at four places, and it will be convenient to give a brief description of each of these with a view to outlining the general habit of the intrusion. We have indicated these exposures on the sketch-map of the dyke (Fig. 1) by Roman numerals, and have utilized Arabic figures to serve as further points of reference. These Arabic figures also denote the places from which rock specimens were collected.

Exposure I.—The most westerly exposure is an old quarry near the road ; this is the best and at the same time the most interesting exposure along the line of the dyke, despite the fact that the old workings are now much obscured by debris and are overgrown by vegetation. The total length of the excavation is about 150 yards, but this includes both a whinstone and a sandstone quarry separated by a thin partition of unworked rock. The dyke runs along the south side of the two quarries and is here very narrow, at the point 2 where both “cheeks” were exposed by hammering its width was rather less than 8 yards. It spreads laterally, however, to form a sill to the north. The limits of the sill cannot be proved ; the apophysis extends along the dyke for at least 60 yards, and is exposed about the same distance to the north of it (point 5). The surface features indicate an extension of the sill for some yards north and west of the quarries, but neither the dyke nor the sill have been proved west of the actual whinstone excavations. With fissile sandstone overlying it the sill is well exposed on the east side of the whinstone quarry, indicated at 3 in the remnant of unworked stone that divides it from the sandstone workings. This face of rock runs almost at right angles to the dyke. The upper surface of the sill as seen in this face is practically horizontal and fairly regular, but it rises to the west and reaches the surface of the ground within a few yards.

Although very little solid rock could be laid bare in the shallow workings between the exposure described and a deep excavation in sandstone at the point marked 4, such rock as could be exposed was wholly sandstone. The north cheek of the dyke was proved in the south side of this deep excavation, and the eastern limit of the

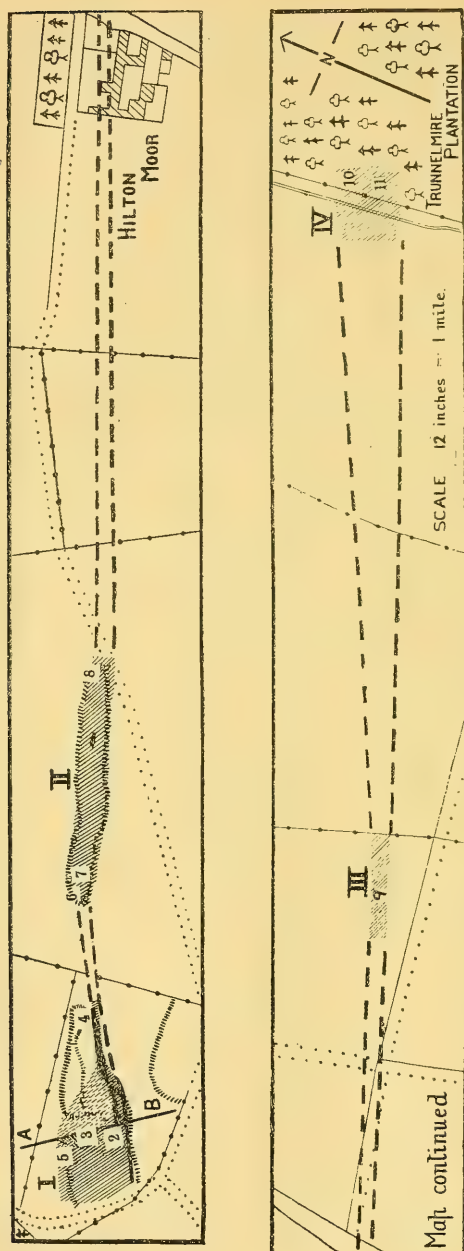


FIG. 1.—Sketch-map of Wackerfield Dyke. Shaded areas represent exposures of the dolerite (broken lines dolerite covered by sandstone). A line bordering shaded areas indicates that the margin of the dyke was there traceable whereas absence of these lines implies the margins were not exposed. A-B indicates line of section (Fig. 2).

sill must therefore closely approximate in position and form with the line we have drawn. The thickness of the sill could not be ascertained as the lower surface is nowhere exposed; the deepest workings are filled with water, but a penetration into whinstone for at least 10 feet is certain.

The rock from the dyke and from the upper part of the sill was much decomposed, particularly so in the latter case; in contact with the overlying sandstone and for a foot or more down it has been changed to a friable ochreous material easily mistakable at first sight for ferruginous sandstone.

Exposure II.—The second exposure is found in a deeper quarry in an adjacent field, less than 100 yards N.E. from the first. The rock is almost completely hidden by debris and soil and consequently the cutting now gives very little information beyond fixing the direction of the dyke and indicating an approximate width. In Exposure I the dyke was striking nearly N.E.—S.W., in this it is running E.N.E.—W.S.W., a direction it continues to follow along the rest of its proved course. The estimated width must closely approach 30 yards. What little rock was actually exposed was wholly dolerite, and this included some remarkably fresh material (6). The freshest samples were obtained near the surface immediately beneath a thin covering of drift.

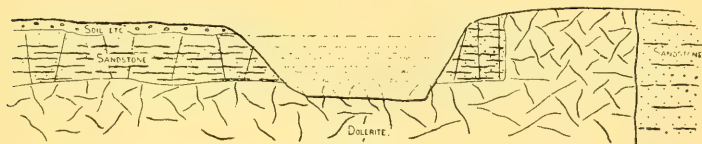


FIG. 2.—Section along A-B (Fig. 1), drawn from southern margin of dyke to middle of face "3".

Exposure III.—This quarry, 250 yards east of Hilton Moor Farm, was "opened out" within recent years, but has since been filled in again. Only a trench-like depression in the ground now marks the position and trend of the dyke, and affords data for a rough estimation of its width, which is evidently about 15 yards. No rock *in situ* can now be seen.

Exposure IV.—The intrusion forms a well-marked feature where it enters Trunnelmire Plantation, but this can only be followed a short distance into the wood. Three or four small trials made just within the plantation have exposed the rock; this is remarkably fresh. The dolerite forms here an outcrop at least 50 yards in width, and unless the dyke is abnormally wide at this point another sill is indicated.

To summarize the information yielded by these exposures: The dyke can be traced for nearly a mile, and with the exception of a deflection near the western end it runs in a straight line; on the other hand it varies considerably in width, and is dilated at both

ends. Continuation beyond the limits shown on the map cannot be proved, and that it persists at the surface is unlikely. At the terminations the intrusion is responsible for marked surface features, but throughout the rest of its course it merely constitutes the backbone of a ridge which is but one of a series with a common trend. The western feature forms the crest of the divide between the rivers before mentioned—the Tees and the Gaunless—but the eastern one lies within the drainage of the latter stream.

THE CLEVELAND AND HETT DYKES.

Before proceeding to discuss the petrological characters of the intrusion and the wider problems which then arise, some brief notice must be taken of the other two dykes which traverse the region, namely, the Cleveland and Hett Dykes.

It will be seen from the map of the area (Fig. 3) that the Wackerfield Dyke, if it persisted only another 500 yards, would cross the path of the Cleveland Dyke, but the latter appears to be absent at the surface between the Bolam and Buck Head laccoliths. There are no surface indications of the Cleveland Dyke between the laccoliths and, moreover, colliery workings have crossed the line of the dyke without encountering the intrusion.

It would be out of place to discuss here, except in bare outline, the habits of this great dyke and the character of its apophyses, particularly as we hope at some future date to deal with the intrusion in detail, but the following facts may be stated. The dyke runs in an E.S.E.-W.N.W. direction from the vicinity of Whitby to the neighbourhood of Carlisle, but it is not persistently present at the surface throughout its long course. East of the Bolam sector, which terminates a mile and a half east of our map, it has not been proved within 14 miles; where next seen it is traversing Triassic beds at Coatham Stob, $3\frac{1}{2}$ miles S.W. of Stockton. Within the neighbourhood with which the present paper is concerned it spreads out into a number of sills and laccoliths; the laccolith north of Bolam village is by far the largest of these. Igneous rock has been injected between the strata on both sides of the dyke along a length of some 1,200 yards. Although the laccolith attains its greatest thickness on the south side of the dyke, its lateral extension is greatest on the north. The igneous sheet is concealed to a very large extent by sandstone and the boundary we have mapped can be merely conjectural. The igneous rock, overlain by sandstone, has been exposed in a small quarry marked "a", nearly 400 yards away from the dyke, and further east a little distance beyond the limits of our map there are traces of whinstone workings 1,200 yards north of the dyke. The stone wrought in the old quarry in question may have been part of the laccolith, or may indicate a branch from the main dyke, the interpretation of the Geological Survey. We have as yet insufficient data to justify any decision.

At Buck Head the injection is wholly on the south side of the

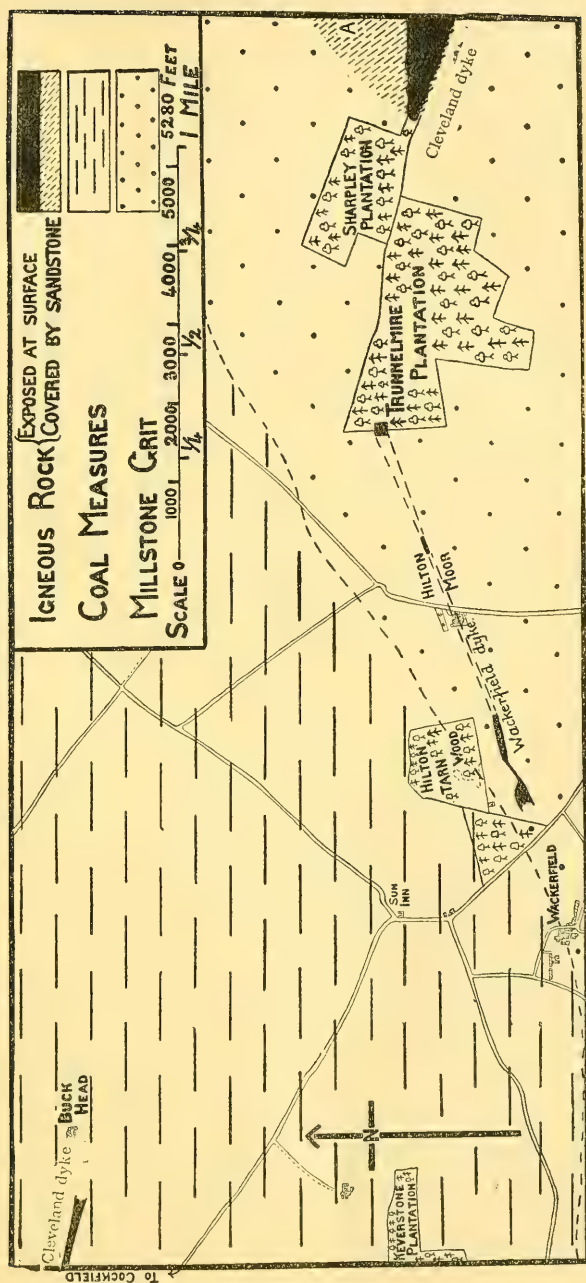


FIG. 3.—Map of country north of Wackerfield

dyke. The laccolith has considerable thickness but is not extensive; it has to some extent the characters of a cedar-tree laccolith. Attenuation of the dyke takes place in proximity to horizontal injection in all cases.

These statements show that the Wackerfield Dyke outcrops on the south side of the more important intrusion but coincides in its extent with a gap in the surface continuity of the great dyke and that both dykes give rise to horizontal offshoots in the same region and in the same manner.

The two dykes are petrologically quite dissimilar and can have no direct genetic relationship. Without anticipating unnecessarily the subsequent section of this paper it may be stated that the Cleveland Dyke has an andesitic character and is of Tertiary Age, whilst the Wackerfield Dyke is a dolerite mineralogically identical with the Whin Sill but of a finer texture. It also resembles the Hett Dyke both in texture and composition, but perhaps less closely so than it does the Whin Sill. Consanguinity between these dykes and the Whin Sill may fairly be assumed and a Carboniferous age argued.

The Hett Dyke, which has the same E.N.E.-W.S.W. bearing as the Wackerfield Dyke, has been traced from the vicinity of Durham to that of Middleton-in-Teesdale, some 25 miles, and has been quarried at many points and for considerable lengths along its course. It is a narrow dyke—at Howden le Wear, where it was followed by one of us for some 2 miles, it only varied in its width from 12 to 18 feet—but runs in a remarkably straight line across the country it traverses.

PETROLOGY.

Megascopic.—The fresh rock of the Wackerfield Dyke is remarkably uniform in appearance throughout the different exposures. It is a dark-grey finely crystalline rock which closely resembles the most commonly occurring variety of the Whin Sill, but the texture becomes somewhat finer near the margins of the intrusion. The rock is altered in places to a buff-coloured material, and between this and the typically fresh rock are intervening stages in which the colours are dull green, purple, and tints of grey. This alteration, although affecting more particularly their contacts, penetrates deeply and irregularly into the dyke and sills. The nature of the alteration is discussed later, and for the present only the fresh rock will be considered. Some dozen specimens were collected for study, and all show an even-grained texture practically free from phenocrysts. Careful examination with a lens reveals a few sparsely distributed phenocrysts of felspar, the longest dimension being about three millimetres, against an average for the bulk of the rock of 0·8 millimetre. The specific gravity varies from 2·90 to 2·98, the actual values for particular specimens being as follows:—

No. 1	6	8	9	10	11
2·96	2·96	2·93	2·97	2·90	2·98

Microscopic.—Under the microscope all the fresh rocks have precisely similar characters, the only detectable variation being in the quantitative proportions of the constituents. The minerals may be considered in four groups: plagioclase, pyroxenes, black ores, and interstitial material. No glass is present, but the interstitial material, which appears to be mainly quartz, occupies many of the wedged-shaped spaces between the essential constituents, and the dominant texture may therefore be described as intersertal. Ophitic relations are also developed in places, though not conspicuously. The characteristic appearance seen in thin section is illustrated by Fig. 1 of Pl. VIII.

Plagioclase.—As in the Whin Sill plagioclase is the most abundant constituent. Except in the marginal facies of the rocks it is perfectly fresh, generally free from inclusions and of prismatic habit, giving lath-shaped and nearly square sections. The smaller prisms are of uniform composition, but larger crystals of the same habit show zoning, while the rare phenocrysts are again uniform but markedly calcic in composition. The smaller prisms constitute the dominant type, and the extinction angles, average refractive index, and specific gravity indicate that its composition is not far from $Ab_{40} An_{60}$. The larger prisms are richer in anorthite in the core, which is often well marked, but the outer layers vary rapidly from labradorite to oligoclase, the peripheral parts having practically the same refractive index as Canada balsam. The range is thus from about $Ab_{30} An_{70}$ to nearly $Ab_{90} An_{10}$. The rare phenocrysts all show irregularly rounded forms suggesting resorption of the original peripheral portions. The internal parts approach anorthite in composition (about $Ab_{10} An_{90}$), and there is little change towards the corroded rim. Irregular streaky inclusions are present as in the larger feldspars of the Whin Sill and the corroded and dislocated feldspar aggregates of the Crookdene and Collywell dykes of Northumberland.¹ Viewed under a high-power objective, the inclusions are found to consist of pyroxene, feldspar, and black ores, suggesting that they were originally blebs of magma which afterwards consolidated inside the feldspars which caught them up.

Miss Heslop and Dr. Smythe suggest that the anorthite aggregates of the Crookdene and Collywell dykes were formed in depth and that they floated up through the magma and thus tended to become concentrated near the head of the dykes, where, in fact, they are found. Viewed in this light, the observations point to the present exposure of the Morpeth Dyke having been the lowest, that is, the farthest removed from the head of the dyke at the time of consolidation; next, in ascending order, comes the Tynemouth Dyke, and, lastly, the dykes of Collywell and Crookdene.”² Although the Wackerfield dyke differs in certain respects from those investigated by Miss Heslop and Dr. Smythe, it appears likely that the

¹ M. K. Heslop & J. A. Smythe, *Q.J.G.S.*, vol. lxvi, 1910, p. 7.

² *Ibid.*, p. 17.

felspar-phenocrysts or enclosures (as they probably are) have had a similar origin and history. Their composition, which is abnormal, and the resorption of their outer parts, show that the crystals were not in equilibrium with the material by which they are now surrounded. They must, therefore, have sunk down or floated up, and both specific gravity evidence and the probabilities of the case point to the latter process as the more probable alternative.

Pyroxenes.—Both orthorhombic and monoclinic pyroxenes are present. Each is of a pale grey-green tint, but there is little difficulty in distinguishing the two species. The orthorhombic pyroxene is only slightly pleochroic, and its composition approaches enstatite rather than hypersthene. It builds stout prismatic crystals of hypidiomorphic outlines, and sometimes occurs as nucleus-crystals, around which aggregates of the monoclinic pyroxenes have grown. The latter are far more abundant than the enstatite and their small optic axial angle indicate that they are not diopside or augite but enstatite-augite. The existence of a series of mixed crystals between clino-enstatite and diopside is now well established, and natural aluminous representatives have been recognized as the characteristic pyroxene of many doleritic rocks. Already in 1884 Sir Jethro Teall, in his masterly study of the Whin Sill, showed by analysis that the monoclinic pyroxene contained approximately nineteen molecules of diopside-hedenbergite to ten of enstatite, with smaller amounts of alumina and ferric oxide. The same type of pyroxene is present in the Wackerfield dyke, and the similarity extends to the mode of occurrence, which is in small grains or larger irregular plates, and to the presence of a fine striation which characterizes certain parts of the larger plates. The colour is grey-green rather than pale brown, but brownish patches occur sporadically suggesting local concentration of iron, and possibly titanium, oxides.

The alteration-products of the two pyroxenes are worthy of attention. The monoclinic pyroxene is sometimes altered to fibrous green actinolite, especially around the borders. The orthorhombic pyroxene, however, tends to be more deeply altered, but only when it occurs as isolated crystals. The alteration-product is a brown fibrous mineral showing strong pleochroism, and giving invariably straight extinction. The birefringence is about 0.020, and it seems clear, therefore, that the mineral is anthophyllite.

Black Ores.—The opaque constituents consist entirely of titaniferous magnetite. From the crushed rock practically the whole of the mineral is abstracted by a bar magnet, and the small second crop obtained by the electro-magnet consists of grains which are largely felspar or augite. In thin section the titaniferous magnetite builds skeletal crystals and also occurs in irregular masses of very different sizes. It encloses both pyroxene and felspar optically and is evidently of comparatively late crystallization.

Interstitial Material.—Between the other minerals, the interstitial spaces, sometimes larger than the average grain-size of the rock, but

generally much smaller and of wedge-like shape, are occupied by a fine granular aggregate, which appears to be mainly quartz. However, it is not wholly quartz, as the material has a pale-green colour, and examination under high power reveals the presence of a fibrous green chloritic mineral and of occasional minute flakes of sericite and rare blebs of a carbonate mineral. In other parts of the rock irregular spaces are occupied mainly by cloudy aggregates of calcite. No true amygdales occur, but it seems likely that the infilling of the final residual spaces represents a late magmatic stage of consolidation corresponding to that which fills the amygdales of the Whin Sill and the Hett dyke. The effects of this stage of the cooling history are seen most conspicuously in the altered peripheral portions of the intrusion.

Other Minerals.—Careful search through a series of thin sections revealed no additional minerals except a clear needle-like crystal of apatite associated with the calcite aggregates. No mica or pyrite has been detected in the fresh rock.

Mineral Analysis.—A series of micrometric analyses by the Delesse-Rosiwal method gave the following percentages by volume. Results for a specimen of the Hett dyke and for two specimens of the Whin Sill are added for comparison.

<i>Minerals.</i>		<i>Wackerfield Dyke.</i>			<i>Hett Dyke.</i> ¹	<i>Whin Sill.</i> ²	<i>Whin Sill.</i> ³
		<i>No. 1.</i>	<i>No. 6.</i>	<i>No. 11.</i>			
Felspars		55·6	54·0	52·7	52·3	53·7	48·9
Pyroxenes		34·5	30·2	31·8	30·8	33·1	39·8
Black Ores		5·2	6·6	7·2	6·8	5·8	7·2
Interstitial		4·7	9·2	8·3	10·1	7·4	4·1
Spec. Grav..	Calculated . .	2·96	2·98	3·01	2·98	2·98	3·04
	Determined . .	2·96	2·96	2·98	2·95	2·94	3·01

The calculated percentages by weight are set forth below, together with the specific gravities (approximate only), used for the groups of minerals measured.

<i>Minerals.</i>	<i>Spec. Grav.</i>	<i>Wackerfield Average.</i>		<i>Hett Dyke.</i>	<i>Whin Sill.</i>	<i>Whin Sill.</i>
		<i>Volume.</i>	<i>Weight.</i>			
Felspars	2·7	54·1	49·0	47·4	48·7	43·4
Pyroxenes	3·2	32·2	34·5	33·0	38·6	41·8
Black Ores	4·8	6·3	10·1	10·8	9·3	11·3
Interstitial	2·6	7·4	6·4	8·8	6·4	3·5

¹ Lunedale, Yorkshire.

² Kirkwhelpington, Northumberland.

³ Greenhead, Northumberland.

These results reveal a remarkable similarity between the rocks investigated, and even though they cannot be considered as strictly accurate, they suggest in a general way a correlative feature to which attention was first directed in a recent paper by one of us (A.H.) on "The Basaltic Rocks of the Arctic Region".¹ It was there shown that in the over-saturated basalts of Iceland and the Faroes the black ores decreased as the feldspars increased, and the same kind of relation, though with a different correlative factor, was found to hold among the olivine-basalts of Iceland. As soon as chemical analyses became available, it was found that the antipathy could be best expressed by comparing titanium dioxide with normative plagioclase, and that a simple relation existed between these constituents which held for nearly all the analysed olivine-free basaltic rocks from Siberia in the north-east to Greenland on the north-west and Mull in the south. The exceptions were found to be somewhat abnormal in texture and composition, as they all contained numerous glomero-porphyrific aggregates of bytownite.

A suggestion of a similar antipathetic relation between feldspars and ores is detectable in the results here presented, as shown by the weight-percentages:—

<i>Feldspars</i> .	43·4	47·4	49·0	48·7
* <i>Black Ores</i> .	11·3	10·8	10·1	9·3

Tested by the available analyses, which unfortunately are few at present, and in the case of the Hett dyke, too poor to be of service, the significant antipathetic variation of titanium dioxide and normative plagioclase is found to hold. And not only so, but the correlative factor approximates so closely to that of the Brito-Arctic unsaturated basaltic rocks that the figures fit into the series with only a very slight discrepancy.

<i>Locality.</i>	<i>Titanium Dioxide.</i>	<i>Normative Plagioclase.</i>
Spitzbergen	2·93	42·56
Mull	2·80	42·42
<i>Whin Sill</i> (B)	2·42	44·83
Franz Josef Land . .	2·29	46·63
<i>Wackerfield</i> (A) . .	2·22	45·36
<i>Whin Sill</i> (C)	1·92	47·21
Kuzkin Island	1·63	51·30
Mull	1·46	59·36
Mull	1·46	61·83
Mull	0·93	66·16

We hope in a later paper to present analyses by means of which the suggested relation may be tested more rigorously. There can be no doubt that the Brito-Arctic Tertiary rocks are derivatives from a regional magma or series of magmas of uniform composition, in which some continuous process of differentiation has brought about the remarkable relation which has been disclosed. It seems probable that by the sinking of olivine crystals a separation of under-

¹ *Min. Mag.*, vol. xvi, 1918, p. 216.

saturated from oversaturated material became possible. Within each type of magma the crystallization and slight upward concentration of plagioclase (lighter than the magma), accompanied and followed by a slight downward concentration of the heavier black ores, would then take place. Such a process, being continuous in depth, but arrested locally by intrusion or eruption, would appear to explain the antipathy between the constituents mentioned. It is suggested that the Wackerfield dyke, the Hett dyke, and the Whin Sill are related by some such community of process, and that they were drawn either from a single uniform magma or from a series of uniform magmas.

Moreover, chemical, mineral, and textural evidence shows not only that the parent magma was similar to that from which the oversaturated Brito-Arctic basalts were derived, but that the processes which acted on each were in all essentials identical. This conclusion does not warrant the deduction that the Whin Sill and the related dykes are of Tertiary age, for that would imply that similar processes acting on similar materials could take place only during a single period of the earth's history. On the contrary, many features of late Carboniferous magmatic history are known to have been repeated in the igneous episodes of the Tertiary, and correlation of process between certain Tertiary rocks and the Whin Sill group must therefore not be confused with correlation in time.

Chemical Composition.—We are indebted to Dr. H. F. Harwood for the following excellent analysis of specimen No. 6 :—

<i>Constituents.</i>	<i>Percentages.</i>	<i>Molecular Proportions.</i>		<i>Norm.</i>	
SiO ₂	50.30	838	Quartz . . .	5.22	
Al ₂ O ₃	14.11	138			
Fe ₂ O ₃	3.16	20	Orthoclase . .	4.38	
FeO	9.90	138	Albite	19.78	
MgO	5.56	139	Anorthite . . .	25.58	
CaO	8.54	153			
Na ₂ O	2.34	38	Diopside . . .	11.40	
K ₂ O	0.74	8	Hypersthene . .	20.40	
H ₂ O (> 105° C.) . .	1.94	—			
H ₂ O (at 105° C.) . .	1.01	—	Magnetite . . .	4.55	
CO ₂	0.16	4	Ilmenite	4.22	
TiO ₂	2.22	28	Apatite	0.61	
P ₂ O ₅	0.30	2	Calcite	0.36	
MnO	0.12	2			
BaO	0.03	—			97.50
SrO	none found	—	Water	2.95	
S	none found	—			
Cl	trace	—	Total	100.45	
ZrO ₂	trace	—			
Total	100.43				
			Specific Gravity }	= 2.98.	

The analysis is recalculated into standard mineral compounds (normative minerals), and restated in this form on the right. The mineralogical characters of the rock are faithfully reflected by the standard mineral composition ; that is to say, the mode is nearly

normative. The normative compositions of plagioclase, pyroxenes, and opaque ore corresponds closely with those revealed by microscopic examination.

The analysis as a whole is that of a typical oversaturated dolerite, and for comparison and contrast it is repeated below, together with analyses of the Whin Sill, of a dyke and lava-flow occurring in Mull, and of the Cleveland dyke.

	A.	B.	C.	D.	E.	F.
SiO ₂	50.30	51.22	50.71	51.63	50.54	57.57
Al ₂ O ₃	14.11	14.06	14.78	11.77	12.86	14.25
Fe ₂ O ₃	3.16	4.32	3.52	3.23	4.13	6.04
FeO	9.90	9.03	8.95	10.52	8.75	3.95
MgO	5.56	4.42	5.90	5.02	4.63	4.24
CaO	8.54	8.33	8.21	9.34	8.74	6.87
Na ₂ O	2.34	2.55	2.76	2.90	2.42	2.98
K ₂ O	0.74	1.25	1.39	0.91	1.43	1.08
H ₂ O +	1.94	1.28	1.78	1.40	2.24	1.25
H ₂ O -	1.01			0.68	0.21	
CO ₂	0.16	0.19	0.25	0.11	0.19	0.30
TiO ₂	2.22	2.42	1.92	2.00	2.80	trace
P ₂ O ₅	0.30	0.25	n.d.	0.29	0.26	0.15
MnO	0.12	0.16	0.31	0.35	0.32	0.27
BaO	0.03	n.d.	n.d.	0.03	n.f.	n.d.
S	n.f.	0.26	n.d.	0.04	n.f.	0.19
Totals	100.43	99.74	100.48	100.28	100.12	99.14
Sp. Gr.	2.98	2.98	2.94	—	—	2.77

A.—Wackerfield Dyke. H. F. Harwood, *analyst*.

B.—Whin Sill. Cauldron Snout, Durham. J. J. H. Teall, *analyst*. *Q.J.G.S.*, xl, 1884, p. 654.

C.—Whin Sill. Craggs near Borecovicus, Northumberland. J. J. H. Teall, *analyst*. *British Petrography*, 1888, p. 209.

D.—Tholeiite of Brunton Type. Dyke near Kintallen Mull. E. G. Radley, *analyst*. *Summ. Prog. Geol. Surv. for 1914, 1915*, p. 55 (Lab. No. 411).

E.—Basaltic lava, Mull. E. G. Radley, *analyst*. *Summ. Prog. Geol. Surv. for 1915, 1916*, p. 26 (Lab. No. 448).

F.—Cleveland Dyke, Great Ayton, Yorkshire. W. F. K. Stock, *analyst*. *British Petrography*, 1888, p. 206.

It will be seen at once from inspection of the first three columns that the composition of the Wackerfield dyke (except in regard to potash) corresponds as closely with that of the Whin Sill as one analysed sample of the Whin Sill does with the other. Chemical evidence, therefore, strongly supports the view of type-identity already recognized by Miss Heslop, and developed here in the preceding paragraphs. The difference in potash is in accordance with the only noteworthy petrographical difference between the Wackerfield dyke and the Whin Sill, namely, the absence of recognizable micropegmatite and biotite from the former. The Hett dyke is petrographically identical with the Wackerfield dyke, but the old analyses which at present are alone available are

incapable of providing a satisfactory basis for chemical comparison. The two analyses of Tertiary rocks from Mull are given to demonstrate the similarity to which reference has already been made.

The Cleveland dyke, like the Whin Sill, is extraordinarily uniform throughout its range, and the uniformity is borne out by a number of fairly good analyses. One of these is quoted in the table above, in order to bring out the fact that it is of andesitic rather than doleritic composition. The Wackerfield dyke evidently belongs to a different suite from that of which the Cleveland dyke is the type. It is possible that between the tholeiite group of the Northumberland dykes, the Whin Sill group, and the Cleveland dyke group there are genetic relations similar to those connecting the tholeiites, cumbraites, leidleites, and inninmorites of the Clyde area.¹ Here, again, differences of geological age have no necessary bearing on the question, but in the absence of sufficient adequate chemical data, discussion of this petrological problem must be deferred.

ALTERATIONS.

As already stated, the dyke-rock does not depart from a uniform type except where the minerals have suffered a marked alteration. This alteration is largely but not entirely marginal, and there the rock is slightly—but very slightly—finer in texture.

Microscopic examination indicates that the alterations are of two distinct kinds: one related to silicification and the other to carbonatization.

Specimen No. 7 (taken from floor of quarry and from near the centre of the dyke at a depth of about 20 feet or more—Exposure I) is typical of the latter. The rock is pale grey with occasional splashes of brown limonitic staining. In thin section it is seen that the pyroxenes are replaced by cloudy granular aggregates of carbonate minerals, penetrated in places by numerous acicular crystals of apatite, and associated with sporadic grains of pyrite. Certain vaguely defined rhombs suggest the presence of dolomite in addition to calcite, and this is confirmed by chemical tests. The feldspars are slightly fogged, but twinning and zoning still remain. Small flakes of biotite have developed, especially between titaniferous magnetite and the interstitial matter, suggesting an interaction between these minerals promoted by the percolating solutions either during or after their attack on the pyroxenes. The interstitial material as a whole remains unaffected.

Specimen No. 4 (from the north cheek of the dyke immediately east of the sill—Exposure I) is a brownish-green rock with a faintly purple coloration here and there. The dominant alteration is the replacement of the feldspars by quartz, chalcedony, and opal. The opal appears in core-like granules and streaks, these, surrounded by chalcedony, give the feldspars a mottled relief due to rapid alternations

¹ G. W. Tyrrell, *Geol. Mag.*, 1917, pp. 305 and 350. See also S. Tsuboi, *Journ. Geol. Soc. Tokyo*, xxv, 1918, p. 47.

of low and medium refractive index, which is very characteristic of silicification. Carbonates are almost wholly absent, and neither apatite nor pyrite have been detected. The pyroxenes and also the opaque minerals are largely replaced by brown limonitic material, but cores of the fresh minerals still remain, together with chloritic borders around the pyroxenes and cream-grey streaks of leucoxene traversing the opaque minerals. The interstitial matter, as before, remains unaltered.

Specimen No. 8 (surface of the dyke, near margin—Exposure II) exhibits the effect of weathering on material of the same type as No. 7. Calcite and dolomite have both been leached out almost completely, while limonite has been leached out in certain parts and concentrated in well-marked bands parallel to the exposed surface.

It is clear that the two processes of alteration are of the same character as those involved in the infilling of the amygdales found in the Whin Sill and the Hett dyke. They represent a late-magmatic (paulopost) and probably hydrothermal stage of the waning magmatic activities, and have nothing to do with weathering, as commonly supposed, although at the same time the material in question is deeply weathered.

The alteration to the margins is evidently a consequence of the contraction of the dyke. The residual liquors, wherever situated, would tend to become concentrated and to move upwards along the channels offering least resistance; that is to say, along the contraction fissures which developed along the margins.

EXPLANATION OF PLATE VIII.

Magnification = 22·5 diameters.

FIG.

- 1.—Typical field of the dolerite of the Wackerfield dyke. Specimen No. 6 from Exposure II. See p. 446 for description.
- 2.—Typical field of the dolerite of the Little Whin Sill, Stanhope. The minerals are identical with those of the Wackerfield dyke, except that the feldspars are slightly turbid. In texture the only difference is that here the feldspar laths are less uniformly dispersed.
- 3.—Corroded phenocryst of bytownite in the Wackerfield dyke. Specimen No. 1 from Exposure I. See p. 447 for description.

The Foraminifera of the Hartwell Clay and Subjacent Beds.

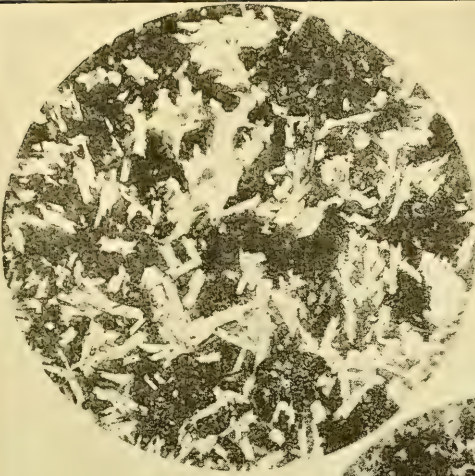
By E. NEAVERSON, M.Sc., F.G.S.

(PLATE IX.)

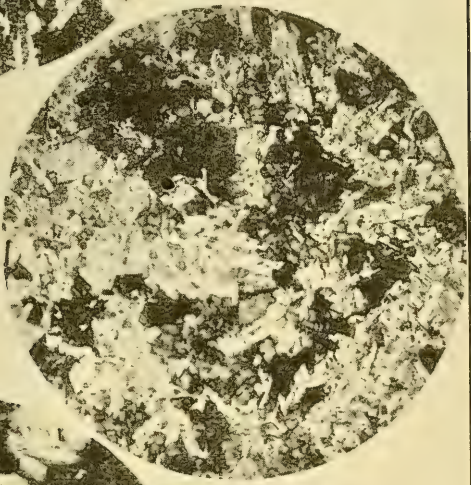
INTRODUCTION.

DURING a temporary cessation of work on the Ammonites of the Hartwell Clay, the writer was asked to identify a series of Foraminifera found by Mr. E. Hollis of the Bucks. County Museum, Aylesbury, in washing a sample of clay from Hartwell. Other samples were collected and examined from all the available

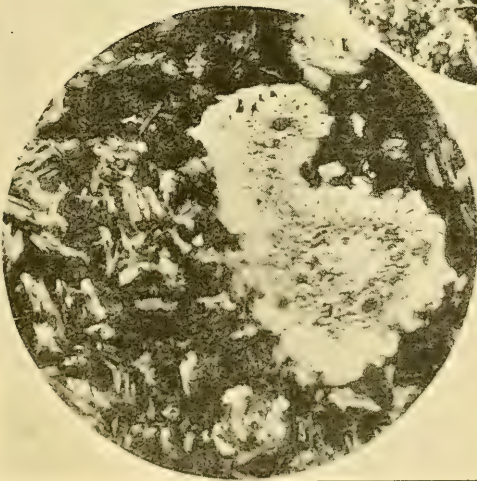
1



2



3



G. S. Sweeting, photo.

PHOTOMICROGRAPHS.

Magnification = 22.5 diameters.

exposures of Hartwell Clay, and the results are given below. A series of the Foraminifera has been deposited in the Aylesbury Museum.

Previously the Foraminifera of this interesting deposit had received scant attention. A short list is given in the Geol. Surv. Memoir by H. B. Woodward (*Middle and Upper Oolites*, 1895, p. 227), but on account of the terminology employed, some revision appears necessary. In 1897 F. Chapman recorded fifteen species from Hartwell (*Proc. Geol. Assoc.*, vol. xv, p. 97), remarking that they "present a facies comparable with that of the Neocomian (*sic*) and Gault". No other lists appear to have been published, and the forms have not yet been described.

Foraminifera from beds of approximately the same age have been described by :—

Chapman (Tithonian Foram. Stramberg; *Linn. Soc. Journ. Zool.*, vol. xxviii, 1900, p. 28);

Perner (Ueber Foram. Tithon, Stramberg; *Bull. Acad. Bohême*, 1898, p. 1); and

Haeusler (Die Astrorhiziden und Lituoliden des Bimammatus Zone; *N. Jahrb.*, 1883, vol. i, p. 55).

Other works consulted are indicated in the text, but the synonymy is reduced to a minimum, only a few of the more important references being given.

The writer is indebted to Mr. E. Hollis for help in the collection and preparation of material, to Mr. S. S. Buckman, Mr. C. P. Chatwin, and Dr. A. Morley Davies for kindly criticism and suggestions, to Professor P. G. H. Boswell for reading the manuscript; also to Dr. F. L. Kitchin for an opportunity recently of examining Chapman's specimens of Gault Foraminifera, now in the Museum of Practical Geology. For this assistance the writer wishes to express his gratitude.

NOTES ON STRATIGRAPHY OF THE BEDS.

A combination of circumstances renders the determination of the zonal sequence in the Hartwell Clay and underlying beds a matter of some difficulty. The number of exposures is limited, some of the brickfields have not been worked for a considerable time, the workings are shallow, and the ammonites usually in a fragmentary condition. The identification of the ammonites also is not yet complete; only a provisional indication of the horizons is therefore given.

The typical Hartwell Clay is exposed at Hartwell, Aylesbury, and Bierton, and contains ammonites usually identified as *Perisphinctes pallasianus* (d'Orb.). This clay is overlain by the Portland Pebble-bed, which has weathered down to a sandy consistency. The clay at Whitchurch (5 miles north of Aylesbury) is probably on the same horizon as that at Hartwell, because, though it differs from the latter in the presence of selenite, fragments of ammonites occur

which seem to be the typical Hartwell forms. The deposit at Long Crendon, near Thame, represents a lower horizon than that usually worked at Hartwell. It contains some of the characteristic Hartwell Clay fossils, but the ammonites present different characters, being large inflated Perisphinctids with fairly coarse ribs. Similar ammonites were found at Hartwell years ago when the workings were deeper. At Wheatley and Shotover Hill the clays contain nodules enclosing ammonites of a still different type—fine-ribbed Perisphinctids involute in youth becoming evolute later; coarse-ribbed species, however, occur at both localities. These clays have until recently been referred to the Kimmeridge Clay, but an examination of the residues has disclosed the presence of glauconite, a mineral which appears to be absent from the typical Kimmeridge Clay of the district.¹ This, and the occurrence of typical Hartwell Clay belemnites in the clay at Wheatley appear to indicate that these beds should be classified with the Hartwell Clay as Bononian.² The following is a summary of the beds under discussion:—

4. Typical Hartwell Clay of Hartwell, Aylesbury, Birtton, and Whitchurch.

3. Hartwell Clay of Long Crendon—a lower horizon than that usually worked at Hartwell.

2. Highest "Kimmeridge Clay" of Wheatley and Shotover Hill—a sandy clay.

1. Blue Clay of Wheatley and Shotover Hill with nodule band as basement bed.

GENERAL CHARACTERS OF THE CLAYS AND OF THE MICROZOA.

The following notes give the general characters of the microzoa; and also of the sediments from the various localities, pending a complete petrographical description.

Hartwell.—Abundant quartz and glauconite grains occur, many of the latter being casts of Foraminifera; marcasite is common, sometimes filling tests of Foraminifera, more often as spherical concretions. Ostracods³ are common, and Foraminifera abundant; hooklets from the tentacles of a belemnoid, remains of echinoderms,⁴ fish-teeth, otoliths, and scales are also found.

Aylesbury and Birtton.—Quartz and glauconite grains are abundant as at Hartwell; spherical concretions of marcasite also are common. Foraminifera and ostracods are common, but the number of species is relatively small.

Whitchurch.—Selenite is the commonest mineral in the residues, occurring often in well-formed crystals. Quartz and glauconite are common, whilst marcasite frequently occurs. Foraminifera

¹ See also A. M. Davies, *Q.J.G.S.*, vol. lxxviii, 1907, p. 36.

² See A. M. Davies, *Introd. to Palæontology*, 1920, p. 385.

³ Chapman, *Proc. Geol. Assoc.*, vol. xv, 1897, p. 97 (list of species).

⁴ Bather, *GEOL. MAG.*, 1916, p. 302.

are relatively rare, probably owing to the abundance of selenite. Ossicles of *Isocrinus* were found here.

Long Crendon.—Abundant quartz and frequent grains of glauconite, but the latter is not so common here as at localities nearer Aylesbury. Ostracods rare, Foraminifera common.

Wheatley and Shotover Hill.—Highest “Kimmeridge Clay”—Quartz grains and small aggregates of marcasite are abundant; glauconite grains occur, but are not common. Foraminifera abundant, ostracods common. Blue clay above nodule band. Quartz grains and small concretions of marcasite are the commonest minerals, whilst glauconite is rare. Foraminifera and ostracods are common.

Speaking generally, the colour of the glauconite of the Hartwell Clay is a rich green, but many grains present a dull yellowish appearance. This yellow colour appears to be due to decomposition, as on boiling with dilute hydrochloric acid the grains become green. The size of the grains is variable, some glauconite being present in each grade-size separated by elutriation, but they do not occur in grades greater than 0.5 mm. diameter, which consist entirely of shell fragments. Exact determinations of the specific gravity of the glauconite have not yet been made, but it is certainly variable. While most of the glauconite has a specific gravity less than 2.8, many grains come down with the heavy detrital minerals separated in bromoform. The grains are usually rounded, but some are sub-angular; many are obviously casts of Foraminifera and occasionally broken specimens of *Cristellaria* have been seen to contain an infilling of glauconite.

This indicates that, although some of the glauconite may be detrital, much is indigenous to the deposit. Similar observations have been made on the glauconite in the Gault of Ford, near Aylesbury, mentioned on a later page. In some samples of the Hartwell Clay, marcasite is most abundant, glauconite being rare. The marcasite occurs as spherical concretions or irregular grains, and often as an infilling in tests of Foraminifera. It would seem that in these cases marcasite has been formed instead of glauconite. It is hoped that more detailed work will show whether these two minerals are connected in any way; for the present no generalization can be made.

THE FORAMINIFERA.

In the following notes the occurrence of the Foraminifera at the localities mentioned is indicated by letters, thus:—

v.r. = very rare.	. 1 to 2 specimens	} in 1 lb. of clay.
r. = rare .	. 3 to 5 „	
f. = frequent .	. 6 to 10 „	
c. = common .	. 10 to 20 „	
a. = abundant	. above 20 „	

Family LITUOLIDÆ.

SUBFAMILY LITUOLINÆ.

REOPHAX, MONTFORT, 1808.

Reophax scorpiurus, Montfort.

Reophax scorpiurus Montfort, 1808; *Conchyl. Système*, vol. i, p. 330, 83^e genre.
Reophax helvetica Haeusler, 1883; *Q.J.G.S.*, vol. xxxix, p. 27, pl. ii, figs. 8-10.
Reophax scorpiurus Sherlock, 1914; *GEOL. MAG.*, p. 221, pl. xviii, fig. 1.

A few specimens appear to belong to this species, but they are small and ill-developed. *R. scorpiurus* has been recorded from the Swiss Jurassic (Haeusler), the Oolite of Fontoy, Moselle (Terquem), the Gault of Folkestone (Chapman), and the Speeton Clay of Yorkshire (Sherlock). At present it has a world-wide distribution at depths varying from 3 to 3,960 fathoms (Brady).

Localities: Hartwell (v.r.); Whitchurch (v.r.); Wheatley, bed 2 (r.); Shotover Hill, bed 1 (v.r.).

HAPLOPHRAGMIUM Reuss, 1860.

Haplophragmium acutidorsatum Hantken.

Haplophragmium acutidorsatum Hantken, 1868; *Magyar földt. tarsulat*, B. 4, S. 82, Taf. i, fig. 1.

H. acutidorsatum Chapman, 1892; *Journ. Roy. Micr. Soc.*, p. 4, pl. v, fig. 11.

This is probably the form recorded by H. B. Woodward from the Lower Portland of Bucks as *Lituola nautiloidea* Lam.¹ It resembles *H. emaciatum* Brady, which, however, is an evolute form, whilst *H. acutidorsatum* is involute. The latter is known from the Tertiaries of Hungary (Hantken) and the Gault of Folkestone (Chapman). *H. emaciatum* is a shallow-water form occurring in the West Indies (Brady).

Localities: Hartwell (c.); Long Crendon (v.r.); Wheatley, bed 2 (v.r.).

Haplophragmium æquale (Roemer).

Spirolina æqualis Roemer, 1840; *Verst. norddeutsch. Kreidegeb.*, p. 98, pl. xv, fig. 27.

Haplophragmium æquale Reuss, 1862; *Sitz. b. Akad. Wiss. Wien*, xlv, p. 29, pl. i, figs. 1-7.

H. æquale Chapman, 1892; *Journ. Roy. Micr. Soc.*, p. 5, pl. vi, figs. 1-3.

One specimen is referred to this species which was first recorded by Roemer from the Chalk of North Germany. It has since been found in the Upper Hills and Speeton Clay of Germany (Reuss) and the Gault of Folkestone (Chapman).

Locality: Long Crendon (v.r.).

Subfamily TROCHAMMININÆ.

THURAMMINA Brady, 1879.

Thurammina albicans Brady. (Pl. IX, Fig. 11.)

Thurammina albicans Brady, 1879; *Q.J. Micr. Soc.*, vol. xix, n.s., p. 27.

T. albicans Brady, 1884; *Chall. Rep.*, vol. ix, p. 323, pl. xxxvii, figs. 2-7.

T. albicans Chapman, 1892; *Journ. Roy. Micr. Soc.*, p. 7, pl. vi, fig. 9.

¹ *Mem. Geol. Surv.*, M. and U. Oolite, 1895, appendix, p. 400.

A few specimens from Hartwell are referred to this species, which is recorded from Upper Jurassic strata of Switzerland (Haeusler) and the Gault of Folkestone (Chapman). At the present day it lives off the coast of South America, best developed at a depth of 1,900 fathoms (Brady).

Locality : Hartwell (r.).

Thurammina papillata Brady.

Thurammina papillata Brady, 1879 ; *Q.J. Micr. Soc.*, vol. xix, N.S., p. 26, pl. v, figs. 4-8.

T. papillata, Haeusler, 1883 ; *Ann. Mag. Nat. Hist.*, ser. v, vol. xi, p. 262, pl. viii.

T. papillata Brady, 1884 ; *Chall. Rep.*, vol. ix, p. 321, pl. xxxvi, figs. 7-18.

Several specimens from the Hartwell Clay seem to belong to this species rather than to *T. albicans*. Their colour is brown, their shape variable, and the surface bears irregularly disposed perforate papillæ : often two or more chambers are mutually adherent. *T. papillata* is recorded from the Upper Jurassic of Switzerland (Haeusler), and at the present day is a deep-water form with a world-wide distribution (Brady).

Localities : Hartwell (f.) ; Long Crendon (v.r.) ; Shotover Hill, bed 1 (v.r.).

Family TEXTULARIIDÆ.

Subfamily TEXTULARIINÆ.

TRITAXIA Reuss, 1860.

Tritaxia ? variabilis (Brady).

Verneuilina variabilis Brady, 1884 ; *Chall. Rep.*, vol. ix, p. 385, pl. xlvii, figs. 21-24.

Chapman recorded this form from Hartwell in 1897, but the present writer has failed to obtain it.

Family LAGENIDÆ.

Subfamily LAGENINÆ.

LAGENA Walker & Boys, 1784.

Lagena hispida Reuss.

Lagena hispida Reuss, 1858 ; *Zeitschr. d. deutsch. geol. Ges.*, vol. x, p. 434.

L. hispida Reuss, 1862 ; *Sitz. k. Akad. Wiss. Wien*, xlv, p. 335, pl. vi, figs. 77-79.

L. hispida Brady, 1884 ; *Chall. Rep.*, vol. ix, p. 459, pl. lvii, figs. 1-4, pl. lix, figs. 2, 5.

This species was originally described from the Oligocene Septaria-clay of Pietzpuhl (Reuss), and Chapman records it from the Gault of Folkestone. Ranging from Lias to Recent, it lives at depths varying from 129 to 1,900 fathoms in many parts of the existing seas (Brady).

Localities : Hartwell (f.) ; Bierton (v.r.).

Lagena lævis (Montague).

Vermiculum læve Montague, 1803 ; *Test. Brit.*, p. 524.

Lagena lævis Brady, 1884 ; *Chall. Rep.*, vol. ix, p. 455, pl. lvi, figs. 7-14, 30.

L. lævis Sherlock, 1914 ; *GEOL. MAG.*, p. 256, pl. xviii, fig. 14.

Lagena clavata (d'Orb.).

Oolina clavata d'Orbigny, 1846; *For. Foss. Vien.*, p. 24, pl. i, figs. 2, 3.

Lagena clavata Reuss., 1862; *Sitz. k. Akad. Wiss. Wien.*, vol. xvi, p. 320, pl. i, figs. 13, 14.

L. clavata Brady, 1884; *Chall. Rep.*, vol. ix, p. 456.

Chapman records *Lagena lævis* from the Hartwell Clay. One specimen, now in the Aylesbury Museum, is referred to *L. clavata*, which is probably a variety of *L. lævis*. This, the only specimen found by the present writer, has a fusiform contour and a pointed base. *L. lævis* is one of the commonest of the *Lagenæ*, and has been recorded from the Woolhope beds (Brady). It occurs at the present day in all latitudes and at all depths down to 2,435 fathoms (Brady). *L. clavata* has a similar distribution (Brady).

Locality: Hartwell (v.r.).

Lagena apiculata (Reuss).

Oolina apiculata Reuss, 1862; *Sitz. k. Akad. Wiss. Wien.*, vol. xvi, p. 319, pl. i, figs. 4-8, 10, 11.

Lagena apiculata Brady, 1884; *Chall. Rep.*, vol. ix, p. 453, pl. lvi, figs. 4, 15-18.

L. apiculata Sherlock, 1914; *GEOL. MAG.*, p. 255, pl. xviii, fig. 12.

Ranging from the Lias to the present day, this form is found abundantly at all depths in existing seas (Brady).

Locality: Hartwell (v.r.).

Lagena sulcata (Walker & Jacob).

Serpula sulcata Walker & Jacob, 1798; *Adam's Essays*, p. 634, pl. xiv, fig. 5.

Lagena sulcata Brady, 1884; *Chall. Rep.*, vol. ix, p. 462, pl. lvii, figs. 23, 26, 33, 34.

Found at the present day in all latitudes at depths down to 2,750 fathoms (Brady), this species is recorded from various strata and occurs as low as Silurian (Brady).

Locality: Hartwell (v.r.).

Subfamily NODOSARIINÆ.

NODOSARIA Lamarck, 1816.

Subgenera *Glandulina* and *Dentalina* d'Orbigny.

Nodosaria (*D.*) *fontannesii* Berthelin.

Dentalina fontannesii Berthelin, 1880; *Mém. Soc. géol. France*, ser. III, vol. i, No. 5, p. 42, pl. ii, fig. 14.

N. (D.) fontannesii Chapman, 1893; *Journ. Roy. Micr. Soc.*, p. 593, pl. ix, fig. 15.

N. (D.) fontannesii Sherlock, 1914; *GEOL. MAG.*, p. 257, pl. xviii, fig. 7.

This species was originally described from the Gault of France (Berthelin), and has since been found in the Folkestone Gault (Chapman), and the Speeton Clay of Yorkshire (Sherlock).

Locality: Hartwell (v.r.).

Nodosaria raphanus (Linn.).

Nautilus raphanus Linné, 1767; *Syst. Nat.*, 12th ed., p. 1164, No. 283.

N. raphanus Linné, 1788; *Syst. Nat.*, 13th ed., p. 3372, No. 16.

Nodosaria raphanus Brady, 1884; *Chall. Rep.*, vol. ix, p. 513, pl. lxiv, figs. 6-10.

This is the most widely distributed species of *Nodosaria* in the Hartwell Clay, occurring at all the localities except Aylesbury. It is recorded by H. B. Woodward as *Nodosaria* cf. *raphanistrum* [Linn.], and the specimens in Aylesbury Museum from the collection of the late Dr. Lee, of Hartwell House, have this label. Chapman records the form as *N. raphanus* from Hartwell. It ranges from the Lias and occurs at the present day at depths down to 1,400 fathoms (Brady).

Localities : Hartwell (c.) ; Bierton (r.) ; Whitchurch (r.) ; Long Crendon (a.) ; Wheatley and Shotover Hill, bed 2 (a.), bed 1 (r.).

Nodosaria seminuda Reuss. (Pl. IX, Fig. 1.)

Dentalina seminuda Reuss, 1850 ; *Denkschr. Akad. Wiss. Wien.*, vol. i, p. 367, pl. xlv, fig. 9.

Nodosaria seminuda Baggs, 1912 ; *U.S. Geol. Surv.*, Bull. 513, p. 59, pl. xvi, fig. 3.

A single well-developed specimen shows similarity with *N. seminuda* Reuss. The lower portion of the test is costate, the later chambers smooth ; the early septa are hardly visible, but the later part of the test is more constricted, the last chamber being almost globular. The species is therefore a catagenetic form, showing loss of ornament (costate to smooth). It lives at present in the Caribbean Sea (Baggs), and does not appear to have been recorded below the Tertiary.

Locality : Hartwell (v.r.).

Nodosaria (Gl.) humilis Roemer. (Pl. IX, Figs. 2, 3.)

N. humilis Roemer, 1841 ; *Verst. norddeutsch. Kreide*, p. 95, pl. xv, fig. 6.

N. humilis Chapman, 1893 ; *Journ. Roy. Micr. Soc.*, p. 585, pl. viii, fig. 18.

This form is very variable in its distribution at different localities. All specimens from Hartwell preserve a regularly conical outline due to the feeble inflation of the segments ; in certain individuals which are much longer, a greater number of chambers is developed than in the type. *N. (Gl.) humilis* has been recorded from the Upper Hils Clay, the Speeton Clay, and Gault of North Germany (Roemer, Reuss), from the Gault of Folkestone (Chapman), and the Gault of France (Berthelin), as well as from later deposits.

Localities : Hartwell (c.) ; Long Crendon (c.) ; Wheatley, bed 2 (v.r.).

FRONDICULARIA DeFrance, 1824.

Frondicularia concinna Koch. (Pl. IX, Fig. 5.)

Frondicularia concinna Koch, 1851 ; *Palaeontographica*, vol. i, p. 172, pl. xxiv, fig. 5.

F. concinna Reuss, 1862 ; *Sitz. k. Akad. Wiss. Wien.*, vol. xlv, p. 54, pl. iv, fig. 13.

The Hartwell Clay specimens differ from the previously figured specimens in that the greatest width is nearer the initial end, and the outline is more irregular. *F. concinna* is recorded from the Upper Hils and Speeton Clay of Germany (Reuss).

Localities : Wheatley, bed 2 (f.) ; Shotover Hill, bed 1 (r.) ; Bierton (v.r.).

Fron dicularia granulata Terquem.

Fron dicularia granulata Terquem, 1863 ; *Mém. Ac. Imp. Metz.*, vol. xlv, p. 379, pl. vi, fig. 20.

Only one specimen of this species was found in the beds under discussion. Previously *F. granulata* has only been recorded from the Lias (Terquem).

Locality : Shotover Hill, bed 1 (v.r.).

MARGINULINA d'Orbigny, 1826.

Marginulina Jonesi Reuss.

Marginulina Jonesi Reuss, 1862 ; *Sitz. k. Akad. Wiss. Wien.*, vol. xlvi, p. 61, pl. v, fig. 19.

M. Jonesi Chapman, 1894 ; *Journ. Roy. Micr. Soc.*, p. 163, pl. iv, fig. 24.

M. Jonesi Sherlock, 1914 ; *GEOL. MAG.*, p. 259, pl. xviii, fig. 15.

The individuals of this form differ considerably with regard to the number of chambers, but on the whole agree well with the published figures. Sherlock regards *M. Jonesi* as "a mere variety of *M. costata* (Batsch) characterized by fewer and more marked ribs", but he retains the specific name. Originally described from the Upper Hils of Germany (Reuss), it has since been found in the Gault of Folkestone (Chapman), the Speeton Clay of Yorkshire (Sherlock), and the Hartwell Clay (Chapman).

Localities : Hartwell (a.) ; Bierton (r.) ; Long Crendon (v.r.) ; Wheatley and Shotover Hill, beds 1 and 2 (c.).

Marginulina linearis Reuss.

Marginulina linearis Reuss, 1862 ; *Sitz. k. Akad. Wiss. Wien.*, vol. xlvi, p. 60, pl. v, fig. 15.

M. linearis Chapman, 1894 ; *Journ. Roy. Micr. Soc.*, p. 161, pl. vi, fig. 14.

This form has been recorded from the *Minimus*-clay of North Germany (Reuss), the French Gault (Berthelin), Gault of Folkestone (Chapman), and the Speeton Clay of Yorkshire (Sherlock). It occurs also in the Oxford Clay of Buckinghamshire (see later).

Localities : Hartwell (r.) ; Shotover Hill, bed 1 (v.r.).

VAGINULINA d'Orbigny, 1826.

Vaginulina discors Koch. (Pl. IX, Fig. 6.)

Vaginulina discors F. Koch, 1851 ; *Palæontographica*, vol. i, p. 172, pl. xxiv, figs. 1, 2.

V. discors Reuss, 1862 ; *Sitz. k. Akad. Wiss. Wien.*, vol. xlvi, p. 50, pl. iii, figs. 10-12.

V. discors Chapman, 1894 ; *Journ. Roy. Micr. Soc.*, p. 426, pl. viii, fig. 13.

Chapman recorded *V. discors* from the Hartwell Clay in 1897. The specimens found by the present writer are characterized by depressed septal lines and striated segments, but they lack the strong longitudinal ribs which are shown in figures by Reuss and Chapman. They differ in this respect also from *V. sparsicostata* Reuss. For the present, however, it seems advisable to retain them under the name *V. discors*, as they agree well with Chapman's

figured specimen from the Gault of Folkestone, now in the Jermyn Street Museum. This species is recorded from the Speeton Clay of Germany (Reuss) and the Gault of Folkestone (Chapman).

Localities: Hartwell (c.), Aylesbury (v.r.), Wheatley, bed 2 (f.), Birtton (r.), Long Crendon (r.).

Vaginulina harpa Roemer. (Pl. IX, Fig. 7.)

Vaginulina harpa Roemer, 1841; *Verst. norddeutsch. Kreide*, p. 96, pl. xv, fig. 13. *V. harpa* Reuss, 1862; *Sitz. k. Akad. Wiss. Wien.*, vol. xlv, p. 51, pl. iv, figs. 5-7.

Specimens from the Hartwell Clay referred to this species are very variable in outline, but the type of ribbing is constant. *V. harpa* is recorded from the Upper Hils and Speeton Clay of Germany (Reuss), the Lower Portland of Bucks (H. B. Woodward), the Hartwell Clay (Chapman), and older Jurassic deposits (see later).

Localities: Hartwell (c.); Aylesbury (f.); Birtton (r.); Whitchurch (f.); Long Crendon (v.r.); Wheatley and Shotover Hill, bed 2 (c.), bed 1 (a.).

Vaginulina incompta Reuss. (Pl. IX, Fig. 4.)

Vaginulina incompta Reuss, 1862; *Sitz. k. Akad. Wiss. Wien.*, vol. xlv, p. 45, pl. iii, fig. 5. *V. incompta* Sherlock, 1914; *Geol. Mag.*, p. 260, pl. xix, fig. 10.

One specimen from the Hartwell Clay is referred to this species, which is recorded from the Upper Hils of Germany (Reuss) and the Speeton Clay of Yorkshire (Sherlock).

Locality: Hartwell (v.r.).

Vaginulina legumen (Linn.).

Nautilus legumen Linné, 1758; *Syst. Nat.*, 10th ed., p. 711, No. 248; 1767, 12th ed., p. 1164, No. 288.

Vaginulina legumen Brady, 1884; *Chall. Rep.*, vol. ix, p. 530, pl. lxvi, figs. 13-15.

This species ranges from Triassic to Recent. It is common in existing seas in shallow water (to 2,000 fath.), and is occasionally found in deep water (Brady).

Locality: Hartwell (v.r.).

CRISTELLARIA Lamarck, 1816.

Cristellaria humilis Reuss.

Cristellaria humilis Reuss, 1862; *Sitz. k. Akad. Wiss. Wien.*, vol. xlv, p. 65, pl. iv, fig. 16, 17.

C. humilis Chapman, 1894; *Journ. Roy. Micr. Soc.*, p. 648, pl. ix, fig. 7.

This form was originally described from the Upper Hils of Germany, and has since been recorded from the Gault of Folkestone (Chapman) and the Hartwell Clay (Chapman).

Localities: Hartwell (c.); Long Crendon (v.r.); Wheatley, bed 2 (f.); Shotover Hill, bed 1 (a.).

Cristellaria italica (Defr.).

Saracenia italica DeFrance, 1824; *Dict. Sci. Nat.*, xxxii, 177; xlvii, 334; *Atlas Conch.*, xiii, 6.

Cristellaria italica Brady, 1884; *Chall. Rep.*, vol. ix, p. 545, pl. lxxviii, figs. 17, 20-23.

C. italica Chapman, 1894; *Journ. Roy. Micr. Soc.*, p. 653, pl. x, fig. 10.

Specimens of *C. italica* from the Hartwell Clay resemble those from the Gault of Folkestone in having sharp edges and a distinct keel. Some elongated specimens approach *C. bononiensis* Berth., but preserve the spiral commencement. Ranging from the Lias upwards, the species has already been recorded from the Hartwell Clay (Chapman). It also occurs in the Gault of Folkestone (Chapman), and the Aptian of Surrey (Chapman). At the present day it is found in shallow water at depths varying from 90 fathoms in the Mediterranean to 725 fathoms in the North Atlantic (Brady).

Localities: Hartwell (a.); Aylesbury (c.); Bierton (c.); Long Crendon (a.); Whitechurch (f.); Wheatley and Shotover Hill, bed 2 (a.), bed 1 (c.).

Cristellaria sulcifera Reuss.

Cristellaria sulcifera Reuss 1862; *Sitz. d. Akad. Wiss. Wien*, vol. xlvi, pp. 74, 93, pl. viii, fig. 8.

C. sulcifera Chapman, 1894; *Journ. Roy. Micr. Soc.*, p. 650, pl. x, fig. 2.

This form often approaches *C. italica*, with which it appears to be connected by transition-forms, but typical specimens are easily distinguished by the grooved sutural lines. *C. sulcifera* has been recorded from the *Minimus*-clay of Germany (Reuss), Aptian of Surrey, Gault of Folkestone, and the Hartwell Clay (Chapman).

Localities: Hartwell (f.); Wheatley, bed 2 (r.).

Cristellaria navicula d'Orb.

Cristellaria navicula d'Orbigny, 1840; *Mém. Soc. Géol. Fr.*, ser. i, vol. iv, p. 27, pl. ii, figs. 19, 20.

C. navicula Reuss, 1845; *Verstein. böhm. Kreidef.*, pt. i, p. 34, pl. xii, fig. 27.

C. navicula Chapman, 1894; *Journ. Roy. Micr. Soc.*, p. 650, pl. x, fig. 1.

Recorded from the Hartwell Clay (Chapman), *C. navicula* occurs in the Gault of Monteley (Berthelin), the Gault of Folkestone (Chapman), and many Upper Cretaceous faunas.

Localities: Hartwell (f.); Long Crendon (v.r.); Wheatley, bed 2 (r.).

Cristellaria convergens Bornemann.

Cristellaria convergens Bornemann, 1855; *Zeitschr. deutsch. geol. Gesellsch.*, vol. vii, p. 327, pl. xiii, figs. 16, 17.

C. convergens Brady, 1884; *Chall. Rep.*, vol. ix, p. 546, pl. lxix, figs. 6, 7.

C. convergens Chapman, 1896; *Journ. Roy. Micr. Soc.*, p. 4, pl. i, fig. 6.

Chapman has already noted this form from Hartwell. It is also recorded from the Tertiary of Hermsdorf (Bornemann), the Gault of Folkestone (Chapman), and the Aptian of Surrey (Chapman). At the present day it is characteristically a deep-water form.

Localities: Hartwell (f.); Aylesbury (v.r.); Long Crendon (f.).

Cristellaria complanata Reuss.

Cristellaria complanata Reuss, 1845; *Verstein. böhm. Kreidef.*, pt. i, p. 33, pl. xiii, fig. 54.

C. complanata Reuss, 1862; *Sitz. k. Akad. Wiss. Wien.*, vol. xlvi, p. 92, pl. xii, fig. 13.

C. complanata Chapman, 1894; *Journ. Roy. Micr. Soc.*, p. 653, pl. x, fig. 12.

Originally described from the Plänermergel of Bohemia, this

species has been recorded from the Gault of Folkestone (Reuss, Chapman), and the Aptian beds of Surrey (Chapman).

Localities: Hartwell (v.r.); Whitchurch (v.r.); Long Crendon (v.r.).

Cristellaria fragraria (Gümbel). (Pl. IX, Figs. 9, 10.)

Margulina fragraria Gümbel, 1868; *Abh. m.-ph. Cl. k.-bayer Ak. Wiss.*, vol. x, p. 635, pl. i, figs. 58a-c.

Cristellaria fragraria Burrows & Holland, 1897; *Proc. Geol. Assoc.*, vol. xv, p. 38, pl. iii.

Numerous specimens from Long Crendon agree with Gümbel's figure 58a, and with the series of figures given by Burrows & Holland. Specimens from Hartwell have a different development in the younger portions of the test which is more elongated and more constricted at the septa, the chambers being more globular (cf. Gümbel's figure 58c). The tubercles which ornamented the earlier septa are not seen in the later part of the test, whereas longitudinal striæ are here developed. Both forms, therefore, agree in showing catagenesis of ornament, from tuberculate to striate, but the later (Hartwell) form exhibits a more advanced degree of uncoiling. *C. fragraria*, which is abundant in the London Clay, has already been noted from the Hartwell Clay (Chapman). It also occurs in the Nummulitic Marl of the Bavarian Alps (Gümbel), and in the *Clavulina Szabói* beds of Hungary (Hantken). Recent specimens were obtained from Torres Str. (155 fath.) and off the coast of S. America (350 fath.) only (Brady).

Localities: Hartwell (a.); Birtton (v.r.); Long Crendon (a.); Wheatley, bed 2 (v.r.).

Cristellaria cultrata (Montfort).

Robulus cultrata Montfort, 1808; *Conchyl. Syst.*, vol. i, p. 214.

Cristellaria cultrata Brady, 1884; *Chall. Rep.*, vol. ix, p. 550, pl. lxx, figs. 4-6.

C. cultrata Sherlock, 1914; *Geol. Mag.*, p. 262, pl. xix, fig. 4.

This species, which ranges from the Lias to the present day, was noted from Hartwell by Chapman. It is a common form and has been recorded from most of the Jurassic and Cretaceous deposits. At the present day it has a world-wide distribution and is found at all depths (Brady).

Localities: Hartwell (a.); Aylesbury (a.); Birtton (a.); Whitchurch (c.); Long Crendon (v.r.); Wheatley (a.); Shotover Hill (r.).

Cristellaria Roemeri Reuss. (Pl. IX, Fig. 8.)

C. Roemeri Reuss, 1862; *Sitz. k. Akad. Wiss. Wien.*, vol. xlv, p. 75, pl. viii, fig. 9.

Numerous rotulate *Cristellarians* with limbate sutures are referred to this species which was found by Reuss in the Middle Hils, Speeton Clay, and *Minimus*-clay of Germany. It does not appear to have been recorded since.

Two specimens from Wheatley show a decided tendency towards uncoiling; these are referred to *C. Roemeri* for the present, until more material is available for study.

Localities : Hartwell (a.) ; Aylesbury (r.) ; Bierton (r.) ; Wheatley, bed 2 (a.).

Cristellaria gibba d'Orb.

C. gibba d'Orbigny, 1839 ; *Foram. Cuba*, p. 63, pl. vii, fig. 20.

C. gibba Brady, 1884 ; *Chall. Rep.*, vol. ix, p. 546, pl. lxxix, figs. 8, 9.

C. gibba Chapman, 1896 ; *Journ. Roy. Micr. Soc.*, p. 4, pl. i, fig. 7.

C. gibba Sherlock, 1914 ; *GEOL. MAG.*, p. 261, pl. xix, fig. 9.

This species ranges from the Lias to the present day, and is recorded from many of the Lower Cretaceous deposits as well as from the Hartwell Clay (Chapman). It is recorded living from the North Atlantic and South Pacific at depths of less than 500 fathoms, "but this is probably only a small portion of the area it inhabits" (Brady).

Localities : Hartwell (c.) ; Long Crendon (f.).

Cristellaria crepidula (F. & M.).

Nautilus crepidula Fichtel & Moll, 1798 ; *Test Micr.*, p. 107, pl. xix, figs. g-i.

Cristellaria crepidula d'Orbigny, 1839 ; *Foram. Cuba*, p. 64, pl. viii, figs. 17-18.

C. crepidula Brady, 1884 ; *Chall. Rep.*, vol. ix, p. 542, pl. lxxvii, figs. 17, 19, 20 ; pl. lxxviii, figs. 1, 2.

C. crepidula Chapman, 1894 ; *Journ. Roy. Micr. Soc.*, p. 648, pl. ix, fig. 8.

Under this name are included the strongly compressed, non-carinate, elongate *Cristellarians*, with depressed septal lines and narrow, almost vertical septal face. The form shows considerable variation of outline, and this variation is so gradual that no strict identification of the numerous "species" can be made. Ranging from the Lias, *C. crepidula* is now found in all existing seas and at all depths, but is nowhere very abundant (Brady).

Localities : Hartwell (c.) ; Bierton (r.) ; Wheatley and Shotover Hill, bed 2 (c.), bed 1 (r.).

Subfamily POLYMORPHINÆ.

POLYMORPHINA d'Orbigny, 1826.

Polymorphina fusiformis Roemer.

Polymorphina (Globulina) fusiformis Roemer, 1838 ; *Neues Jahrb.*, p. 386, pl. iii, fig. 37.

P. fusiformis Chapman, 1896 ; *Journ. Roy. Micr. Soc.*, p. 11, pl. ii, fig. 9.

P. fusiformis Sherlock, 1914 ; *GEOL. MAG.*, p. 263, pl. xix, fig. 12.

The question of nomenclature of this variable form has been discussed by Chapman (1896, p. 11) and Sherlock (1914, p. 264). The species is recorded from the Upper Hils and *Minimus*-clay of Germany (Reuss), Gault of France (Berthelin), and the Gault of Folkestone (Chapman). It still lives at depths down to 2,400 fathoms (Brady).

Localities : Hartwell (v.r.) ; Wheatley, bed 2 (v.r.) ; Shotover Hill, bed 1 (v.r.).

Family GLOBIGERINIDÆ.

GLOBIGERINA d'Orbigny, 1826.

Globigerina marginata, Reuss.

Rosalina marginata Reuss, 1845; *Verstein. böhm. Kreid.*, pt. i, p. 36, pl. xiii, fig. 47.

Globigerina marginata Reuss, 1874; In Geinitz, *Palæontographica*, xx (2), p. 112, No. 2.

G. marginata Brady, 1879; *Q.J.M.S.*, vol. xix, n.s., p. 74.

G. marginata Brady, 1884; *Chall. Rep.*, vol. ix, p. 597.

This form, which closely resembles its isomorph *Pulvinulina menardi* d'Orb., is recorded from Hartwell by Chapman. It was previously restricted to the Cretaceous as a fossil form, being found originally in the Chalk of Bohemia (Reuss). It is very rare in Recent deposits (Brady).

Localities: Hartwell (f.); Wheatley, bed 2 (a.).

Globigerina cretacea d'Orb.

Globigerina cretacea d'Orbigny, 1840; *Mém. Soc. Géol. Fr.*, ser. I, vol. iv, p. 34, pl. iii, figs. 12-14.

G. cretacea Chapman, 1896; *Journ. Roy. Micr. Soc.*, p. 588, pl. xiii, figs. 5, 6.

Several small specimens are placed in this species, which is a characteristic Cretaceous form. It is common in all zones of the Gault of Folkestone (Chapman), and ranges into modern times (Brady). This is the first record of the species below the Cretaceous.

Locality: Hartwell (f.).

Family ROTALIIDÆ.

Subfamily ROTALIINÆ.

PULVINULINA Parker & Jones, 1862.

One specimen from Long Crendon belongs to this genus, but it is so badly worn that specific determination is not possible. The rarity of *Pulvinulina* in the Hartwell Clay is in sharp contrast with the abundance of the genus in the Speeton Clay of Yorkshire.

COMPARISON WITH OTHER DEPOSITS OF THE DISTRICT.

For purposes of comparison various deposits near Aylesbury were examined for Foraminifera, and the results are given below:—

Lower Gault.—Ford, 4 miles S.W. of Aylesbury. Dark-blue clay with abundant grains of quartz, glauconite, and phosphatic material, formerly worked for "coprolites". Over 130 species of Foraminifera were found by the writer and Mr. Hollis, of Aylesbury.¹ There are minor differences in distribution as compared with the Gault Foraminifera from Folkestone. The following fourteen species occur in the Gault at Ford and also in the Hartwell Clay. *Reophax scorpiurus* Montf. (v.r.); *Haplophragmium acutidorsatum* Hantken (f.); *Thurammina albicans* Brady (r.); *Nodosaria* (Gl.) *humilis* Roem. (r.); *N. (D.) fontannesii* Berth. (v.r.); *Marginulina linearis* Reuss (r.); *M. Jonesi* Reuss (r.); *Cristellaria humilis* Reuss (v.r.); *C. navicula*

¹ *The Naturalist*, July, 1921, pp. 235-240.

d'Orb. (v.r.); *C. sulcifera* Reuss (v.r.); *C. italica* (Defr.) (v.r.); *C. gibba* d'Orb. (f.); *C. complanata* Reuss (v.r.); *Polymorphina fusiformis* (Roem.) (f.); The commonest species are *Anomalina ammonoides* (Reuss) and *Globigerina cretacea* d'Orb., which outnumber all the other species put together. Mr. Hollis has prepared a series for the Bucks County Museum at Aylesbury.

Upper Portland.—Long Crendon. A cream-coloured marl, locally known as "Wychert" or "Witchet", was examined, but yielded no Foraminifera. Ostracods are plentiful.

Kimmeridge Clay (latissima-beds).—Stewkley. Dark shale which could not be satisfactorily broken up. No Foraminifera were found.

Kimmeridge Clay (virgula-beds).—Brill. A small sample of the clay sent to the writer contained a few Foraminifera, but the relative abundance cannot be judged on such scanty material. The following species occur: *Haplophragmium* sp.; *Nodosaria raphanus* (Linn.); *Vaginulina harpa* Roem.; *Cristellaria italica* (Defr.); *C. crepidula* (F. & M.); *C. rotulata* (Lam.); *Pulvinulina* sp. Dr. A. Morley Davies¹ has noted Foraminifera from this locality, but they were not identified specifically. The five species fully identified above occur also in the Hartwell Clay.

Oxford Clay (pre-cordatum zone).—Quainton Road Junction. A sandy clay containing much quartz yielded abundant Foraminifera. The list of species is given in full, as the Oxford Clay forms do not appear to have been recorded previously.

Species and relative abundance in the Oxford Clay of Quainton (Bucks).			Geological range as previously recorded.
* <i>Haplophragmium</i> cf. <i>æquale</i> (Roem.)	a.		L. Cretaceous.
<i>Nodosaria communis</i>	v.r.		Permian to Recent.
<i>Lingulina carinata</i>	c.		Lias to Recent.
<i>Fronicularia</i> cf. <i>varians</i> Terquem .	f.		Lias.
<i>Flabellina Deslongchampsii</i> Terquem	f.		Lias.
<i>Rhabdogonium</i> sp.	r.		
<i>Marginulina linearis</i> Reuss.	f.		L. Cretaceous.
* <i>Vaginulina harpa</i> Roem.	f.		Hartwell Clay—L. Cret.
" cf. <i>discors</i> Koch.	r.		Hartwell Clay—Gault.
* <i>Cristellaria crepidula</i> (F. & M.) . .	c.		Lias to Recent.
* " <i>cultrata</i> (Montf.)	f.		Lias to Recent.
" <i>gracillissima</i> Reuss	v.r.		L. Cretaceous.
" <i>gibba</i> d'Orbigny	c.		Lias to Recent.
* <i>Polymorphina fusiformis</i> Roemer .	f.		Lias to Recent.
<i>Vitriwebbina irregularis</i> (Auctt.) .	a.		Lias to Oxford Clay.
<i>Pulvinulina</i> sp.	a.		

* Occurs also in the Hartwell Clay.

GENERAL CONCLUSIONS.

The Foraminifera from the Hartwell Clay above described comprise thirty-seven species belonging to thirteen genera, and may be tabulated as follows:—

¹ *Q.J.G.S.*, vol. lxiii, 1907, p. 32.

		Number of species.	
		Chapman, 1897.	Neaverson, 1921.
LITUOLIDÆ.	<i>Reophax</i> . . .	—	1
	<i>Haplophragmium</i> . . .	—	2
	<i>Thurammina</i> . . .	—	2
TEXTULARIIDÆ.	<i>Tritaxia</i> . . .	1	—
LAGENIDÆ.	<i>Lagena</i> . . .	1	4
	<i>Nodosaria</i> . . .	1	4
	<i>Fronicularia</i> . . .	—	2
	<i>Marginulina</i> . . .	1	2
	<i>Vaginulina</i> . . .	2	4
	<i>Cristellaria</i> . . .	8	11
	<i>Polymorphina</i> . . .	—	1
GLOBIGERINIDÆ.	<i>Globigerina</i> . . .	1	2
ROTALIIDÆ.	<i>Pulvinulina</i> . . .	—	1
		7 genera.	12 genera.
		15 species.	36 species.

In order to analyse the results Chapman's list (*Proc. Geol. Assoc.*, vol. xv, 1897, p. 97) is merged with the new record, as the Hartwell forms have not been fully described before.

Thirty-seven species of Foraminifera have been found in the Hartwell Clay and associated clays. Of these one form is not specifically identified, so will not be further considered. Thirteen (or 36 per cent) of the remaining thirty-six species were recorded from Jurassic deposits older than the Hartwell Clay, whilst twenty-three (or 64 per cent) were not known below the Cretaceous before the publication of Chapman's list. Further, twenty-two of the thirty-six species occur in the Gault of Folkestone, twelve in the Bargate Beds (Aptian) of Surrey, ten in the Speeton Clay of Yorkshire, and thirteen in the Lower Cretaceous of Germany. This confirms Chapman's general statement that the Foraminifera of the Hartwell Clay "present a facies comparable with that of the Neocomian (*sic*) and Gault". The relation is seen more especially with regard to the *Cristellariæ*, which are represented in the Hartwell Clay by eleven species, eight of which are characteristic Lower Cretaceous forms. Other Hartwell forms connecting with the Lower Cretaceous are *Globigerina marginata*, *Vaginulina incompta*, and *Haplophragmium acutidorsatum*. The *Vaginulinæ*, however, present a general Jurassic facies; the commonest species, *V. harpa*, with its strong longitudinal ribbing, forming a marked contrast with the typical *Vaginulinæ* of the Gault which possess projecting sutures and marginal angles. In *V. discors* of the Hartwell Clay the longitudinal ribbing is not so conspicuous, but the limbate sutures and margins are still lacking. *Cristellaria* and *Vaginulina* are the dominant genera in the Hartwell Clay, and it is interesting to find the former represented by Cretaceous species, whilst the latter genus has a Jurassic aspect.

It is more difficult to compare the Hartwell Clay Foraminifera with those from older Jurassic deposits, as the latter have been somewhat neglected. The series from the Kimmeridge Clay and Oxford Clay of Bucks show a marked difference in the assemblage

of Cristellarians. In these deposits the ensiform Cristellarians abound, whilst the rotulate varieties (which predominate in the Hartwell Clay) are subordinate. The occurrence (though rare) of *Cristellaria gracillissima* in the Oxford Clay is noteworthy, as its previous lowest record is from the Speeton Clay of Yorkshire (Sherlock, 1914). The only common *Vaginulina* in the Oxford and Kimmeridge Clays of Bucks is *V. harpa*, though *V. discors* also occurs. These belong to the group with strong longitudinal ribs which, according to Berthelin, had its maximum development in Jurassic times. *Marginulina linearis* occurs in both the Hartwell Clay and the Oxford Clay of Bucks; this is the first record of the species below the Speeton Clay.

A noteworthy feature of the Oxford Clay Foraminifera from Quanton is the great abundance of the arenaceous form, *Haplophragmium* cf. *aequale*, which exceeds in numbers all the other species collectively. In the Hartwell Clay arenaceous forms are uncommon. Porcellaneous forms are not found in the Hartwell Clay, but the Gault of Ford is remarkably rich in *Spiroloculina* and *Miliolina*, whilst *Vitriwebbina irregularis* is abundant in the Oxford Clay of Quanton. Thus the main features of the foraminiferal assemblages may be tabulated as follows:—

<i>Bucks, deposits.</i>	<i>Cristellaria.</i>	<i>Vaginulina.</i>	<i>Arenacea.</i>	<i>Porcellanea.</i>
Gault.	Rotulate varieties.	Limbate and marginate.	Rare.	<i>Spiroloculina</i> and <i>Miliolina</i> .
Hartwell Clay.	Rotulate varieties.	Longitudinally ribbed.	Rare.	None.
Oxford Clay.	Ensiform varieties.	Longitudinally ribbed.	<i>Haplophragmium</i> cf. <i>aequale</i> , abundant.	<i>Webbina irregularis</i> Auctt.

A distinctive feature of the Hartwell Clay assemblage is the frequent occurrence of *Cristellaria fragraria*, which has hitherto been regarded as a characteristic Tertiary form. It is common at two horizons in the Hartwell Clay, and specimens from the higher bed show a more advanced degree of outcoiling than those from the lower. The occurrence of similar forms at widely separated horizons suggests that these forms should not be included under the same specific name. They may be "morphic equivalents" arising from different stocks and thus analogous with homœomorphic forms of Ammonites which are at least generically distinct. This question cannot be decided until more is known of the evolution and development of the Foraminifera.

The Tithonian Stramberg limestone, a deposit of approximately the same age as the Hartwell Clay, contains fourteen species belonging to seven genera.¹ The dominant forms are two arenaceous species (*Ammodiscus incertus* and *Involutina remesiara*) and the cosmopolitan

¹ Chapman, *Linn. Soc. Journ. Zool.*, vol. xxviii, 1900, p. 28. Perner, *Bull. Acad. Sci. Bohême*, 1898, p. 1.

TABLE SHOWING DISTRIBUTION OF THE FORAMINIFERA OF THE HARTWELL CLAY IN SOME OTHER DEPOSITS.

	Species.	Range in time as previously known.	Depth (in fathoms) now living.	Gault, Folkestone.	Apian, Surrey.	Specton Clay, York- shire.	Lower Cretaceous of Germany.	Oxford Clay, Bucks.
1.	<i>Reophax scorpiurus</i> Montf.	Jur.-Rec.	Any.	1		1		
2.	<i>Haplophragmium acutidorsatum</i> Hantken.	L. Cret.-Rec.	Shallow.	2	2			
3.	<i>H. æquale</i> (Roem.)	L. Cret.	—	3			3	3
4.	<i>Thurammina albicans</i> , Brady .	U. Jur.-Rec.	1,900.	4				
5.	<i>T. papillata</i> Brady	U. Jur.-Rec.	Deep water.					
6.	<i>Tritaxia</i> (?) <i>variabilis</i> (Brady) .	Hartwell Clay to Rec.	Shallow.					
7.	<i>Lagena hispida</i> Reuss. . . .	M. Lias.-Rec.	To 1900.	7				
8.	<i>L. lævis</i> (Montague)	Sil.-Rec.	Any.	8	8	8		
9.	<i>L. sulcata</i> (Walker & Jacob) .	Sil.-Rec.	To 2,750.					
10.	<i>L. apiculata</i> Reuss	Lias.-Rec.	To 2,750.					
11.	<i>Nodosaria raphanus</i> (Linn.) .	U. Trias.-Rec.	To 1,400.					
12.	<i>N. seminuda</i> Reuss	Plioc.-Rec.	Shallow.					
13.	<i>N. (D.) fontannesii</i> Berthelin .	L. Cret.	—	13	13	13		
14.	<i>N. (Gl.) humilis</i> Roem. . . .	Lias.-Eocene.	—	14			14	
15.	<i>Fronidularia concinna</i> Reuss. .	Cretaceous.	—				15	
16.	<i>F. granulata</i> Terq.	Lias.	—					
17.	<i>Marginulina Jonesi</i> Reuss . .	Hartwell Clay to Chalk Marl.	—	17	17	17	17	
18.	<i>M. linearis</i> Reuss.	L. Cret.	—	18	18	18	18	18
19.	<i>Vaginulina incompta</i> Reuss .	L. Cret.	—			19	19	
20.	<i>V. legumen</i> (Linn.)	Lias.-Rec.	To 2,000.		20			
21.	<i>V. harpa</i> Roem.	Hartwell Clay— L. Cret.	—				21	21
22.	<i>V. discors</i> Koch	Hartwell Clay— Gault.	—	22			22	22
23.	<i>Cristellaria italica</i> (Deufr.).	Hartwell Clay— Recent.	To 725.	23	23			
24.	<i>C. navicula</i> d'Orb.	Hartwell Clay— Chalk.	—	24				
25.	<i>C. sulcifera</i> (Reuss)	Hartwell Clay to Gault.	—	25	25		25	25
26.	<i>C. fragraria</i> (Gümbel) . . .	Hartwell Clay— Recent.	155 (Torres St. 350 (S. Amer.)					
27.	<i>C. humilis</i> Reuss	Hartwell Clay— Gault.	—	27			27	
28.	<i>C. convergens</i> Born.	Hartwell Clay— Rec.	Deep water.	28	28			
29.	<i>C. cultrata</i> (Montf.)	Lias.-Rec.	rarely < 100	29	29	29		29
30.	<i>C. Roemeri</i> Reuss	L. Cret.	—				30	
31.	<i>C. gibba</i> d'Orb.	Lias.-Rec.	< 500	31	31	31	31	
32.	<i>C. complanata</i> (Reuss) . . .	L. Cret.	—	32	32			
33.	<i>C. crepidula</i> (Fitchel & Moll)	Lias.-Rec.	To 2,350.	33	33	33		33
34.	<i>Polymorphina fusiformis</i> (Roem.)	Lias.-Rec.	To 2,400.	34		34	34	34
35.	<i>Globigerina marginata</i> (Reuss) .	Cretaceous.						
36.	<i>G. cretacea</i> d'Orb.	Cret.-Rec.	Any.	36	36			

species, *Cristellaria rotulata*, *C. gibba*, and *C. cultrata*. A specimen of *Vaginulina truncata* and one of *Haplophragmium neocomianum* connect the assemblage with the Lower Cretaceous. The only point of comparison with the Hartwell Clay is in the occurrence of the *Cristellarians* mentioned above. The Upper Jurassic of Switzerland has yielded arenaceous forms referred by Haeusler to *Thurammina albicans*, and similar forms are occasionally found in the Hartwell Clay.

Of the thirty-six species from the Hartwell Clay, thirteen (or 36 per cent) are known from the Hils of Germany. The foraminiferal assemblages of the two deposits are connected by (1) the dominance of *Cristellaria* and *Vaginulina*, and (2) the comparative rarity of arenaceous forms. A notable difference is the presence of twelve species of *Nodosaria* in the Hils against four in the Hartwell Clay. *Lagena* is not represented in the Hils assemblage, but four species occur in the Hartwell Clay.

The Foraminifera throw little light upon the question of the depth at which the Hartwell Clay was deposited. Nineteen of the thirty-six species are still living and eleven of these are recorded by Brady from both shallow and deep water. Of the eight species remaining, three, *Thurammina albicans*, *T. papillata*, and *Cristellaria convergens*, are characteristic of deep water, whilst five occur in shallow water. The balance of the evidence seems to be in favour of fairly deep water, since tests of shallow water forms could sink to the level of deposition. The Hartwell Clay itself shows great similarity with the Gault Clay both in the abundance of glauconite and in the presence of certain species of Foraminifera. Thus it is permissible to suppose that the depth of deposition would be similar, viz. between 800 and 900 fathoms according to Chapman's calculation for the depth of the Gault Sea.¹

SUMMARY.

1. Thirty-six species of Foraminifera are recorded from various localities in the Hartwell Clay and associated beds.

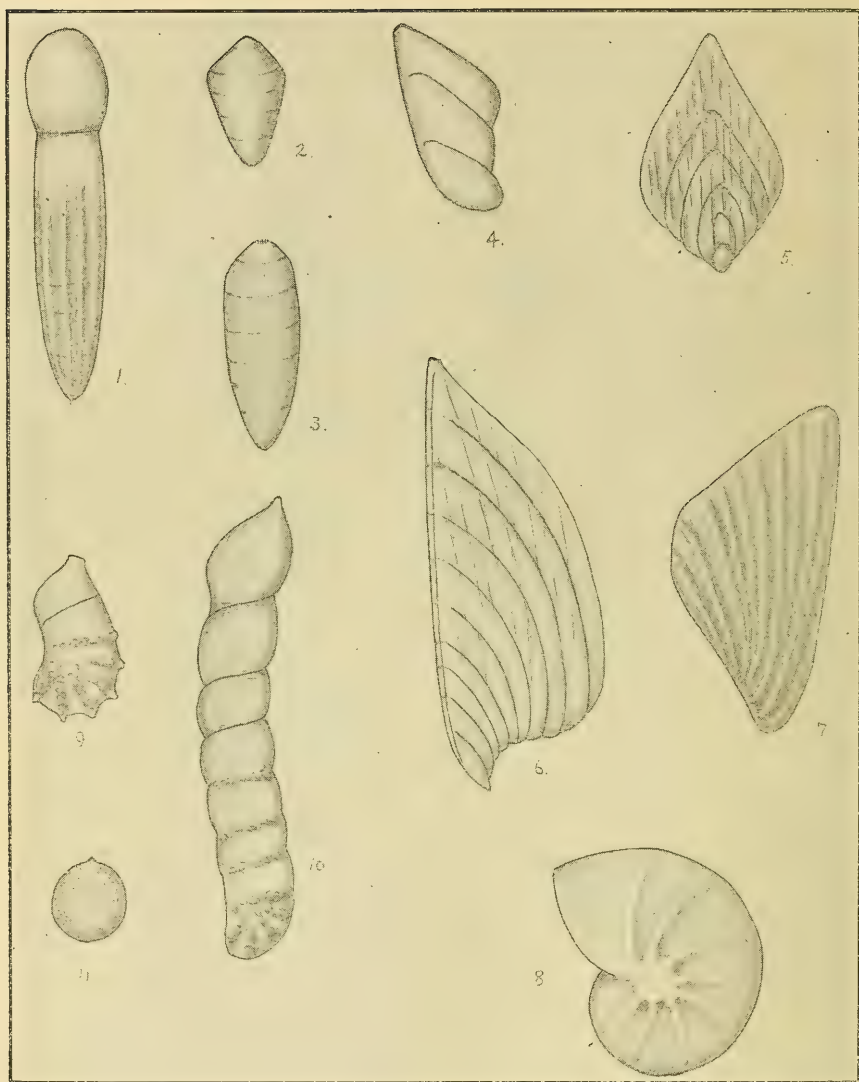
2. The assemblage of species is characterized by:—

- (a) the abundance of rotulate *Cristellarians* of Lower Cretaceous type, and of *Cristellaria fragraria*.
- (b) the common occurrence of *Vaginulina harpa*, a Jurassic type.
- (c) the rarity of arenaceous, and the absence of porcellaneous forms.

3. The Foraminifera from the Hartwell Clay are compared with those from other deposits in the Aylesbury district, and with those from foreign deposits of similar age.

4. The relative abundance of glauconite is a point of similarity between the Hartwell Clay and beds hitherto regarded as Kimmeridge Clay.

¹ *Nat. Sci.*, vol. xiii, 1898, No. 81, p. 305.



E. Neaverson, del. ad nat.

FORAMINIFERA, HARTWELL CLAY, BUCKS.

To face p. 473.]

EXPLANATION OF PLATE IX.

Photograph of *camera lucida* drawings of Foraminifera. All figures are magnified 30 diameters.

Figs.

- 1.—*Nodosaria seminuda* Reuss. Hartwell Clay, Hartwell.
- 2.—*N. (Gl.) humilis* Roemer. Hartwell Clay, Long Crendon.
- 3.—*N. (Gl.) humilis* Roemer. Hartwell Clay, Hartwell.
- 4.—*Vaginulina incompta* Reuss. Hartwell Clay, Hartwell.
- 5.—*Fron dicularia concinna* Reuss. "Kimmeridge Clay," Wheatley.
- 6.—*Vaginulina discors* Koch. Hartwell Clay, Hartwell.
- 7.—*V. harpa* Roemer. Hartwell Clay, Long Crendon.
- 8.—*Cristellaria Roemeri* Reuss. Hartwell Clay, Hartwell.
- 9.—*C. fragraria* Gümbel (short form). Hartwell Clay, Long Crendon.
- 10.—*C. fragraria* Gümbel (long form). Hartwell Clay, Hartwell.
- 11.—*Thurammina albicans* Brady. Hartwell Clay, Hartwell.

NOTE.—A series of specimens is deposited in the Bucks County Museum, Aylesbury, and therefore only a few of the more characteristic forms are figured here.

On a Local Alteration in Limestone Shales at Wensley, Derbyshire.

By C. S. GARNETT.

A SMALL stream forms the boundary between the Parishes of Wensley and Winster, on the north-west of the former; and hereabouts its bed, in the Limestone Shale, is probably about 30 feet above the Carboniferous Limestone. On the Winster side, the shales form a wooded slope (Whites Wood) rising 100 feet in about 200 feet, and on this side the shale is quite normal and of the black colour usual in the lower beds of this formation. On the Wensley side the ground rises more gradually, and the actual bank of the stream averages not more than about 10 feet in height. Here, an altered shale is exposed and can be traced (through the activity of moles) in the fields behind.

There appear to be two small areas of alteration, just over 100 yards apart; and in the case of the larger, of a traceable area of about $\frac{1}{2}$ acre.

At the place of the larger exposure the shale beds are thrown upwards and lie in a confused manner—not unlike the upward bursting caused by the weight of hills behind. On this (the south) side the ground gradually rises from just under 500 feet at the level of the stream, to 1,000 feet in just under half a mile; on the opposite side it rises to 800 feet in a quarter of a mile.

In the areas under consideration the shale in its upper beds, instead of being black in colour, appears bright brick-red from a little distance, and on closer examination is found to be almost white or of a buffish tint within the laminae, whilst at the surface of these it is quite bright red. This distribution of colouring matter is best seen in the harder portions; where the shale was softer the redness is more evenly distributed in the clay, but the red colouring matter is in places almost or quite absent. The black carbonaceous matter has been completely removed, and

ferruginous substances of the shale—although almost unnoticeable in the normal regions—have been completely changed to the red oxide which remains in a very finely divided state. In some of the material the redness is very vivid, but more than 4% of ferric oxide is seldom present.

As is well known, the Limestone Shales frequently contain, especially towards their base, thin beds of black, earthy limestone; the blackness being, of course, due to carbonaceous (bituminous) matter as in the case of the shales, which, normally, are black at this horizon. A thin slab of this limestone which occurred about the margin of the region of alteration, was itself also bleached in a similar manner. It was grey in colour, almost free from carbonaceous matter, and contained faint streaks and spots of red oxide of iron—evidently resulting from the oxidation of ferruginous matter which previously existed in the rock.

Small phosphatic nodules also occur in some abundance in the Limestone Shales of this district; normally, they are somewhat hard, and in colour uniformly almost black throughout. Some are calcareous and contain about 63% tricalcic phosphate, about 20% calcium carbonate, 3% silica, and some carbonaceous matter. To the unaided vision they show no definite structure, although having a somewhat crystalline appearance. Others are almost free from carbonates; they are harder and consist of compact amorphous calcium phosphate (tricalcic phosphate about 63%) with 20% of silica, and are rather more black in colour. It might be here mentioned that much of the calcium phosphate in the calcareous nodules is seen by microscopical examination not to consist of the amorphous substance, as is the case in the non-calcareous ones and phosphatic nodules generally, but it exists as minute crystalline spherulitic masses of definite material—presumably a variety of apatite.

The nodules which occur in the altered region are themselves also altered in a manner exactly similar to that of the shale. Those which have been completely altered are white throughout, and are soft and friable. In these the carbonaceous matter has been completely removed, and also the carbonates and some phosphate. There remains a white mass containing the siliceous matter, varying amounts of phosphate and also a little sulphate. Although completely altered nodules are not plentiful, two types of incomplete alteration occur abundantly. In one type—that of the originally calcareous nodules—they are soft and friable; the carbonates have been removed, also most of the carbonaceous matter, but not yet much phosphate. On being broken they present a speckled appearance. In the other type—that of the non-calcareous nodules, which in the normal condition are very hard and dense—these nodules occurring in the region of alteration, show an unaltered interior; the bleaching action has been very complete so far as it has proceeded, but this is often only to a depth of about $\frac{1}{8}$ or $\frac{1}{4}$ in. and the zone of alteration is comparatively sharply defined.

In the case of the actual shale also there are two exactly similar types of incomplete alteration. Very occasionally only hard, compact shale laminæ are found which contain a small unaltered portion at their centres; the altering agency not having penetrated so far. The other, entire but incompletely changed, condition is common at the margins. As has been mentioned, at the greatest exposure the beds lie in a confused manner; portions of unaltered black beds have become involved in the altered region, which seems to have consisted of surface beds to a depth of several feet. Alteration continued to take place after the portions of unchanged beds came in contact with the changed ones, but only to a small extent, for at the margins of the black portions the decarbonization can be readily seen to have gradually proceeded a short distance inwards. In this case the shale was soft and readily permeable, and shows a gradual transition in greyness from the edge of the mass to several inches inwards, where visible action is lost. A similar transition may be traced in the actually altered beds, though very much more gradually, as they pass from the region of alteration.

The phenomena of the occurrence very closely correspond with those of burning; i.e. combustion with the complete removal of all carbonaceous matter and oxidation of ferruginous substances.

The nearest known occurrence of igneous rock may be expected at about 150 feet below the top of the limestone, that is, about 180 feet below the surface at this place; it was cut through in the old Mill Close shaft, about $\frac{1}{2}$ mile approximately north-east of the occurrence under consideration, but it has been found to be a contemporaneous flow, and could not be the cause of the burning.

Spontaneous combustion arising from the oxidation of pyrites would seem to be the explanation of the occurrence. However, one or two somewhat peculiar features were noticed, and some work was conducted under the supervision of the author in an endeavour to obtain as much elucidation as possible of available evidence.

In the case of the mass of normal (black) shale in the altered zone, the change is seen to have proceeded distinctly further along the planes of bedding than against them. The mass in question happens to be pushed well into the altered region, but it almost retains the normal horizontal position of the bedding; a small crack had formed almost vertically near its centre, and in this, a commencement of apparently the same change in the shale had taken place, diminishing in extent as it passed downwards exactly as would be expected if the change had been brought about through the action of percolating water.

The question arises, what weathering agent could produce the vast chemical changes involved? From the changes which have taken place in the calcareous phosphatic nodules there is a suggestion of slight acidity—by sulphuric acid, but on consideration the more conspicuous changes would seem to be that of very powerful oxidizing action; indeed, a “wet combustion”. Hydrogen peroxide or

ozone in dilute aqueous solution seem to be probably the only agents capable of such vigorous action—at least, under the natural conditions here prevailing.

Wad contains a quantity of manganese dioxide, and, as is well known, the action of sulphuric acid on this results in the liberation of oxygen containing ozone.

Some of the extremely numerous mineral veins in the limestone of the Winster district are famous in Derbyshire for the wad which they contain. Other minerals which are abundant in some of the local veins are pyrites and marcasite, and the readiness with which these are oxidized, with the formation of sulphuric acid as one of the products, is well known. Large quantities of forms of the hydrated ferric oxides also occur in the veins, and much of this is probably of such origin.

Manganese dioxide is not usually regarded as being suitably constituted for the production of hydrogen peroxide, but if it is formed in small quantity, as well as ozonated oxygen by the reaction between the acid and wad, and is carried forward in dilute solution, its action on the organic matter might be expected to be similar to, though less powerful than, that of ozone.

Although ozone is well known to be a most powerful oxidizing substance which attacks and rapidly destroys organic matter, some normal shale was tested with ozone in the laboratory. The shale was crushed and suspended in water, through which oxygen containing ozone was passed in the cold. The ozone readily attacked the organic matter of the shale, with the production of carbon dioxide, and the ready and complete disappearance of all ozone. "Control" experiments were conducted in order that any possible mistaken results would be excluded.

Ozone (or improbably hydrogen peroxide) can be shown (by means of a mixed solution of starch and potassium iodide) to be readily formed by the action of extremely dilute sulphuric acid upon wad; the ozone (and oxygen) entirely passing into solution. Thus, sulphuric acid derived as suggested, on coming in contact with wad, might be expected to give rise to the production of ozone, the solubility of which, in water, is considerable.

On the south of the occurrence of altered shale, which is near the margin of the onset of the shale upon the limestone, the latter rises to 500 feet above the occurrence within half a mile of it. On this slope are almost innumerable small veins containing any or all of the minerals described. The natural drainage level of this area is, of course, the stream mentioned, the former bed of which abruptly marks the horizontal limit of the alteration in this direction. Vertically also, the level of the original bed seems to mark the limit in depth of the alteration, by a rapid but gradual transition. Just above the stream level, in the midst of a completely altered horizon, and between bedding planes of the shale, the action of the slow flowing of percolating water was very noticeable.

If ozone, derived as suggested, was responsible for any of the phenomena noted, perhaps it might be expected that some compound of manganese would be found in the altered zone, and such is the case; clayey matter heavily impregnated with brown oxide of manganese is to be found in some quantity among the altered beds.

Thus, whilst the general phenomena are those of combustion of spontaneous origin such as may arise from the oxidation of pyrites, some of the observations described would perhaps seem to be rather the effect of active percolating water. The actual shales hereabouts do not contain either pyrites or the products of its oxidation in any appreciable quantity, and the ferric oxide in the altered shale is somewhat uniformly distributed in the latter and does not exceed 4%. Thus, if combustion spontaneously arose in such manner, it would seem to have probably done so at a place in closer contact with the limestone veins, and as at the place of exposure the altered beds overlie normal shale at probably about 30 feet above the limestone, the fire would seem to have spread horizontally from such place, which, as the dip is somewhat steep, would be not far distant but would probably involve its passage for a short distance under some beds of shale, leaving them normal and unaltered. The occurrence of brown oxide of manganese in some quantity in the position would be a singular coincidence if simple combustion was the, or the only, cause of the phenomena. Also, with regard to the phosphatic nodules, to account for the condition of the completely altered examples would seem to require some agency other than simple combustion, namely, at least a dilute sulphuric acid solution, and all such examples were found at an obvious water course in the strata at a low horizon in the altered beds.

REVIEWS.

THE GEOLOGY OF THE SOUTH WALES COALFIELD. Part XIII: THE COUNTRY AROUND PEMBROKE AND TENBY. Being an account of the region comprised in Sheets 244 and 245 of the map. By E. E. L. DIXON, B.Sc., F.G.S. Memoirs of the Geological Survey. pp. i-vi, 1-220, with 5 plates, 12 maps, and 1 section. 1921. Price 8s. net.

THIS memoir concludes the series devoted to the description of the maps of the revised survey of the South Wales Coalfield. The introduction contains an admirable account of the physical structure of the area, and is followed by a detailed account of the rocks in the order of their formation. The Lower Palæozoic rocks are found in two important anticlines. Upper and Lower Llanvirn, Wenlock, and Ludlow formations are represented, those of Silurian age being of the type characteristic of South Wales.

The Devonian rocks are of great interest. Both Lower and Upper Old Red Sandstone occur, the former with Pteraspids, the latter with *Holoptychius*. The upper beds are discordant to the lower. In the upper group occur the Skrinkle beds, an interbedded marine and continental series. These Skrinkle beds were briefly noticed in the memoir of the country around Milford in 1916, but full details appear in the present memoir. The marine fauna agrees with that of the Baggy beds, and the containing rocks are, therefore, as surmised by Salter, of Devonian age, even if, as seems to be the case, the Pelton beds must be removed to the Carboniferous system.

The Lower Carboniferous beds apparently show a complete succession from "K" to "D 3". The description is based upon the classification of Vaughan, whose labours in these rocks have been so successfully taken up by the author of the memoir, and the account of the rocks is of the utmost importance to students of the system. "Reef-structures" are described in the division C, and the author appears to favour their contemporaneous origin. The Upper Carboniferous rocks are almost entirely referable to the Millstone Grit, a small patch of Coal-measures appearing only at the northern border. The lower part of the Millstone Grit series contains the well-known Radiolarian cherts, and a fauna of part of the Pendleside series. The highest beds have yielded a Westphalian flora.

Of Mesozoic rocks no true deposits are found, but some remarkable "gash-breccias" are almost certainly of Triassic age. They are regarded as due to collapse and infilling of cavities eroded by underground waters.

Certain pipe-clays at Flimston are considered as being of Tertiary age, and probably the equivalent of the Bovey Tracy beds; while certain gravels with quartz pebbles may be relics of Pliocene river-deposits.

A very important chapter is devoted to tectonics. Evidence is given of many periods of earth-movement, greatest stress being laid

upon the Armorican movements, which produced folding, faulting, cleavage, shearing, and jointing. The most important cross-faults give evidence of lateral movement. The Pleistocene accumulations consist of the well-known raised beach, cave-deposits, and glacial accumulations. The raised beach is regarded by Dewey as interglacial, and the existence of glacial deposits older than the beach is "slightly suggested at two places" in this area. The relations of the beach to the cave-deposits with Pleistocene mammals "do not appear to have been established beyond doubt". Glacial deposits newer than the raised beach consist of gravels and loamy and gravelly boulder-clay.

The latest formations are river-terraces, a submerged forest, alluvium, blown sand, and shingle beaches. Much light has been thrown on the organisms and human artefacts of the submerged forest group by the labours of A. L. Leach.

A brief chapter on economics closes the memoir, though, as stated in the Director's preface, "few deposits of economic importance occur within the boundaries" of the district. Notwithstanding this, the work recorded in this and the previous memoirs of the area around the South Wales Coalfield, especially those parts referring to tectonics, will no doubt be of the utmost utility in helping to solve economic problems in the future. These memoirs, indeed, are an admirable illustration of the value of the work of the Survey in aiding economic geology indirectly as well as directly. We feel confident that Dr. Flett's hope "that this district will be recognized by students and teachers of geology as a typical area for the study of the formations represented, as developed in the south-west of Wales," will be fulfilled, and are glad to note that he calls attention to the fact that copies of the 6 in. maps "may be seen at the offices of the Survey, where also the fossils collected may be examined".

Students and teachers, and, indeed, all other geologists, may be congratulated that a district so interesting alike for its physiography and its geology is elucidated by so excellent a memoir. Mr. Dixon has produced a work of high merit, well got up, well illustrated, and at a price that compares favourably with that of some of the memoirs of the latter part of the last century.

J. E. M.

FLUORSPAR (1913-1919). Imperial Mineral Resources Bureau Digests. pp. 18. 1921. Price 9d.

FLUORSPAR has always been a favourite mineral with collectors, mainly on account of the variety and beauty of the specimens obtainable. Its origin also presents problems of much interest to the petrologist and student of ore-deposits. Of late years it has also become of considerable technical importance, as a flux in the making of steel by the basic open-hearth process, in the preparation of electrolytes used in the reduction of aluminium ores, and for

enamelling iron ware. Fluorite of optical quality is rare and of considerable value.

This pamphlet gives a résumé of the production of fluorspar in the different countries of the world : it is chiefly mined in England and in the United States, lesser quantities coming from Canada, South Africa, New South Wales, France, Austria, and Germany. In 1918 the output of fluorspar in the United States was no less than 235,551 tons, valued at over a million dollars, while in the same year England produced 53,498 tons, chiefly from Derbyshire. There are also important deposits in Durham, Cumberland, and Northumberland.

FIELD MAPPING FOR THE OIL GEOLOGIST. By C. A. WARNER.
pp. x + 145, with 40 figures. New York: Wiley. 1921.
Price 13s. 6d. net.

THIS small but expensive book deals with the methods of field mapping as applied specially to oil geology; nevertheless, much of it is of general application. A useful account is given of the different kinds of maps employed as a basis of field work, and full descriptions of plane tables and other instruments are set out, with instructions for their use. The author rightly lays stress on the value of underground contour or subsurface maps, a part of the subject usually neglected in English textbooks, although of immense importance in mining and oil geology. Nearly half the book is occupied by tables of various kinds, partly mathematical, partly the geological formations of the oil-bearing regions of the United States.

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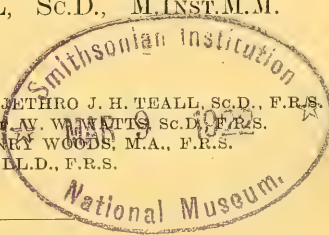
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NOVEMBER, 1921.

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THE GEOLOGICAL MAGAZINE

VOLUME LVIII.

No. XI.—NOVEMBER, 1921.

OBITUARY.

Henry Woodward.

BORN 24TH NOVEMBER, 1832. DIED 6TH SEPTEMBER, 1921.

HENRY WOODWARD was born at Norwich on 24th November, 1832, the youngest son of Samuel Woodward, the well-known geologist and antiquary. His father died when he was 6 years old, and his early life was spent under difficult circumstances. He was educated at the Norwich Grammar School until the age of 14, when he left to accompany his brother, Samuel Pickworth Woodward, to Cirencester, where the latter was beginning his career as Professor of Natural History in the Royal Agricultural College. Henry Woodward was by inclination a naturalist from the beginning, and at Cirencester he had the opportunity of making systematic studies. In 1848 he removed to London with his brother, who was then appointed assistant in the Geological Department of the British Museum. Here he attempted to obtain congenial occupation, which would at the same time maintain him, but in 1851 he felt obliged to return to Norwich, where he spent seven years as a clerk in Gurney's Bank. At last, in 1858, he realized his ambition, and became an assistant in the Geological Department of the British Museum, of which he was eventually Keeper from 1880 until 1901.

As an officer of the British Museum, Henry Woodward devoted himself most assiduously to curatorial work, and when the collection of fossils was removed to South Kensington at the beginning of his Keepership, he planned and supervised the whole of the rearrangement in the new building. He made the public galleries more attractive by adding illustrative diagrams and descriptive labels, and he improved the guide-books by providing them with figures of important specimens. He also increased the value of the collections for the progress of science by planning and editing a series of catalogues, among which may be specially mentioned Etheridge and Carpenter's *Blastoidea*, Hinde's *Fossil Sponges*, Smith Woodward's *Fossil Fishes*, and Lydekker's *Fossil Reptiles, Birds, and Mammals*. His genial personality and helpful ways attracted an increasing number of scientific visitors, and as a result of his efforts the extent and scope of the collections enlarged with greater rapidity than at any previous time. He acquired not only

an immense mass of material for research, but also numerous particularly fine specimens which would be instructive for the public exhibition. Among the more important acquisitions were Williamson's Carboniferous Plants, Davidson's Brachiopods, Nicholson's Stromatoporoids, Stürtz's Devonian Starfishes, Egerton and Enniskillen's Fishes, Lewis' Lebanon Fishes, Leeds' Oxfordian Reptiles, and Forsyth Major's Pliocene Mammals from Samos.

In 1864 Henry Woodward joined Professor T. Rupert Jones in founding the GEOLOGICAL MAGAZINE, and from July, 1865, until the end of 1918 he was sole editor. It is unnecessary to refer to the influence of this serial on the progress of research—it is sufficient to repeat the common saying that almost every British recruit to geology since 1864 has begun authorship in its pages. Under Woodward's judicious and tactful editorial direction, it always welcomed and published honest work, whether on orthodox lines or otherwise; and it afforded a medium for discussion not to be found elsewhere. If his well-laid plans and methods are followed, the MAGAZINE cannot fail to continue its usefulness—provided, of course, that the new generation is willing to give it the same financial support as its predecessors.

Soon after he joined the staff of the British Museum, Henry Woodward began to write notes on newly acquired fossils, which were of general interest. Among these his account of the primitive Jurassic bird, *Archaeopteryx*, in the *Intellectual Observer* for 1862, must be specially mentioned. After the foundation of the GEOLOGICAL MAGAZINE, most of his notes were contributed to its pages, and one of these, in the first volume, on the skull of a mammoth found at Ilford, is particularly memorable. In this communication the first well-preserved skull of an English mammoth is noticed, and as soon as the specimen was mounted in 1868 he pointed out the true inward curvature of the tusks, which showed that in the published figures of the Siberian mammoth in Petrograd the tusks were reversed. In 1869 he wrote on the peaty deposits in the Lea valley, in which numerous Holocene mammalian remains had just been found. In this, and in a later paper, published by the Essex Field Club in 1882, he emphasized the geological importance of the work of beavers, both in the Lea valley and in the Fenland. In 1874, in a paper read before the Geological Society, he discussed the fossil links between birds and reptiles, and referred to the footprints of bipedal reptiles in the lithographic stone of Solenhofen, Bavaria. In 1885, to the same Society, he gave an account of a skeleton of the gigantic extinct Sirenian, *Rhytina*, which had recently been acquired by the British Museum.

Henry Woodward's chief contributions to science, however, were his descriptive memoirs and papers on fossil Crustacea and other Arthropods, on which he became a leading authority. The first of his long series of original papers, on a new macrurous Crustacean from the Lower Lias of Lyme Regis, was published by the Geological

Society in 1863. From 1865 to 1875 he contributed an annual report on British fossil Crustacea to the British Association, and made many advances in knowledge of the subject. In 1864 he exhibited to the British Association at Bath some restorations of the strange Devonian Merostomata, and for many years devoted special attention to this group, which he described in a monograph issued by the Palæontographical Society 1866–78. He pointed out the relationship of the Eurypterids to the existing Xiphosura (king crabs) more clearly than it had been done previously. He also contemplated continuing Salter's unfinished work on the British Trilobites, but unfortunately completed only one small volume on the Carboniferous genera (Palæontographical Society, 1883–4). He joined Professor Rupert Jones in a monograph of the British Palæozoic Phyllopoda (Phyllocarida), likewise published by the Palæontographical Society in 1888. Early in his career he prepared a useful Chart of Fossil Crustacea, with the aid of Mr. J. W. Salter; and in 1877 he summarized all that was known of British Fossil Crustacea in a British Museum Catalogue. During more recent years he also published much on the Carboniferous Arachnids, Myriapods, and Insects, especially from the English Coal Measures. All his papers were well illustrated, many by his daughters.

Henry Woodward occasionally described other invertebrate fossils besides Arthropods, and among his contributions to the GEOLOGICAL MAGAZINE are accounts of Tertiary shells from Sumatra (1879), Palæozoic fossils from Beechey Island (1878), and a well-preserved cuttle-fish from the Chalk of Mount Lebanon (1883).

Almost all Henry Woodward's writings may be described as bringing together useful materials for science rather than as finished contributions. He rarely did more than state the facts and make a few obvious comparisons. He always hesitated to deal with principles, and although he admitted the general truth of the doctrine of evolution, he left to others its application to palæontological research. At the same time he encouraged younger students to adopt the new methods, and he was ever eager to help them with his learning and judicious criticism. He realized the possibility of formulating at least some laws; he only insisted on tempering scientific enthusiasm with discretion.

In 1857 Henry Woodward married Miss Ellen Sophia Page, of Norwich, who took a keen interest in his work, and gave him much help until her death in 1913. Readers of the GEOLOGICAL MAGAZINE remember with gratitude her valuable index to the first forty volumes, which was published in 1905. Of the two sons, both already dead, Harry P. Woodward was for several years Government Geologist of West Australia, while Martin F. Woodward began a promising career as a zoologist. Of the five daughters, Miss Gertrude M. Woodward has long been known for her beautiful illustrations of fossils and zoological specimens in the works of many authors.

Henry Woodward took a very active share in the work of the Geological Society. He was elected a Fellow in 1864, was awarded

the Wollaston Fund in 1866, the Lyell Fund in 1879, the Murchison Medal in 1884, became President in 1894, and received the Wollaston Medal in 1906. He was also an early member of the Geologists' Association, became President in 1873, and from 1875 onwards was an honorary member. He joined the Palæontographical Society at the beginning of his career, and in 1895 he succeeded Professor Huxley as President, retaining this office until his death. He was President of Section C of the British Association at Manchester in 1887. He was the first President of the Malacological Society in 1893, and he served two years as President of the Royal Microscopical Society in 1903-4. For many years he was also an active Vice-President of the Zoological Society. He was elected a Fellow of the Royal Society in 1873, and received the honorary degree of LL.D. from St. Andrews in 1878. He was an honorary member of many other Societies at home and abroad. In all his activities he was a cheery colleague, tactful and sympathetic and full of resource, and his loss is mourned by a large circle of devoted friends.

ORIGINAL ARTICLES.

The Magnesian Group of Igneous Rocks¹

By F. DIXEY, M.Sc., F.G.S., Government Geologist of Sierra Leone.

1. Introduction.
2. Description of the Magnesian Group.
3. The Magnesian Provinces.
4. Age of the Magnesian Group.
5. Origin of the Magnesian Group.
6. Relation to well-known Suites and Series.

I. INTRODUCTION.

ROCKS rich in magnesium are abundantly developed in a certain few areas of the world, whereas they are rare or absent in the remaining areas. With reference to the abundance of magnesian rocks in Southern India, for example, Holland has stated² :—

The most remarkable feature which has been revealed by the recent microscopic study of the crystalline rocks in Southern India is the very great predominance of the pyroxenes (and especially of the rhombic forms of that group) amongst the ferro-magnesian silicates. In addition to the series described in this paper [Charnockite Series], which is probably the most abundant of all the rock groups in the southern portion of Peninsular India, and in every variety of which hypersthene is a constant and characteristic constituent, the central and eastern parts of the Madras Presidency are cut through by an enormous number of basic dykes, in which rhombic pyroxene is also a leading mineral. Judging thus by the mineralogical composition of the rocks, which is confirmed by the few chemical analyses that have so far been made, the bases magnesia and ferrous oxide must take an unusually prominent place amongst the chemical constituents of the southern portion of the Peninsula. Besides occurring as a constituent of the enstatites, which are so widely distributed through the Madras rocks, magnesia appears in even larger proportions in the peridotites, which, either as dunites, saxonites, picrites, or their decomposed forms magnesite, serpentine, and steatite, are now known to be far more abundant than was suspected at the time of the first recognition of these highly magnesian ultra-basic rocks near Salem in 1892.

Again, Lacroix has given a description of two series of analogous igneous rocks in West Africa; the first of these, the gabbro-peridotite series of French Guinea,³ to which probably belongs the enormous noritic intrusion of the Sierra Leone Peninsula,⁴ is characterized throughout by abundance of magnesian minerals, while the second,⁵ a series comparable with the Charnockite Series of

¹ Paper read before Section C (Geology) of the British Association for the Advancement of Science, Edinburgh Meeting, September, 1921.

² "Charnockite Series of Igneous Rocks": *Mem. Geol. Surv. India*, vol. xxviii, 1900, p. 192.

³ M. A. Lacroix, "Les Syénites Nephelinique de l'Archipel de Los": *Nouv. Arch. du Mus. d'Hist. Nat., Paris*, 5ème Serie, Tome 3, 1911, p. 108.

⁴ F. Dixey, "The Norite of Sierra Leone": *Abs. Proc. Geol. Soc.*, 1921, p. 103.

⁵ M. A. Lacroix, "Sur l'Existence à la Côte d'Ivoire d'une Série Petrographique comparable à celle de la Charnockite": *Comptes Rendus Hebdom. des Séances de l'Acad. des Sci.*, 150, 1910, p. 18.

India, although characterized in all members by hypersthene, is especially rich in this and other magnesian minerals in the less acid members. Recent work of the Geological Survey of Sierra Leone¹ has shown that these two series of rocks, in addition to huge masses of talc-schist, amphibolite, etc., are well represented in Sierra Leone also.

Thus it is seen that Southern India is largely composed of enormous masses of rocks belonging to the Charnockite Series, of associated peridotites and their altered equivalents, and of later noritic and pyroxenic dykes, and also that the older igneous rocks of at least the central and western parts of West Africa consist of a similar assemblage; these two areas may be considered as exhibiting typical developments of the group of igneous rocks now under consideration. A number of analogous areas will be cited in a later paragraph.

II. DESCRIPTION OF THE MAGNESIAN GROUP.

Since the principal characteristic of these rocks is their richness in magnesium, it is proposed to distinguish them as a Magnesian Group of igneous rocks.² The term "group" is used in preference to "series" because, as will be shown below, the rocks in question include some or all of the members of certain series already recognized, and also because it is at present uncertain how far they form a continuous series in themselves. The rocks of this group give rise in various parts of the world to a limited number of Magnesian Provinces, of which West Africa may be taken as a good example, as indicated in the preceding paragraph. The term "Province" is here used essentially in a geographical sense, although, as will be seen below, the principal members of the group are of Archaean or very early age; moreover, although the rocks of any one of the provinces do not necessarily belong to one igneous epoch, they are, nevertheless, related in important mineralogical and chemical characters.

It is, of course, recognized that highly magnesian rocks have occurred in all ages as differentiates of large intrusions of less basic composition; in the present paper, however, consideration is given essentially to the large magnesian intrusions, such as those of India referred to above, that apparently possess a separate existence. In all probability differentiation of some kind operated even in the production of these large intrusions, but this differentiation took place on a very large scale indeed, giving rise to the great crustal "shells" referred to below.

¹ F. Dixey, *Reps. Geol. Surv., Sierra Leone*, 1919-20.

² Note.—An analogous arrangement has been suggested by Washington with regard to a small group of rocks, characterized by high content of titanium, which he proposes to distinguish as a "Titanium Province". See H. S. Washington, "The Titaniferous Basalts of the Western Mediterranean": *Q.J.G.S.*, vol. lxiii, 1907, p. 69.

The distinguishing features of the Magnesian Group may be summarized as follows :—

Texturally, these rocks are often granular, and they are generally well-banded.

Chemically, the rocks are rich in magnesium and in iron, especially in the less siliceous varieties; the abundance of these two constituents, combined with fairly low alumina and lime, leads to the persistence of hypersthene. There is wide variation in the content of silica.

Mineralogically, the rocks are almost invariably characterized by the presence of hypersthene, and a monoclinic magnesia-pyroxene sometimes accompanies and may even replace the hypersthene; moreover, common augite is generally an important constituent. Olivine is often abundant in the more basic members of the group. Garnet is a common and sometimes abundant constituent, particularly amongst the older rocks.

Concerning the presence of garnets in the Charnockite Series of India, an important member of the Magnesian Group, Holland has stated ¹ :—

The prevalence of garnets in some members of the Charnockite Series which show no signs of dynamo-metamorphism, suggests that although pyroxene is the stable form of the same compound at low temperatures, there is an intermediate but high temperature, short of fusion, at which either hornblende or pyroxene breaks up into a more basic garnet and a more siliceous by-product, quartz or felspar. It is to such a cause that the prevalence of garnets in these old pyroxenic rocks should be ascribed.²

Stillwell,³ however, regards the peculiar mineralogical features of the Charnockite Series as due to recrystallization in the kata zone of metamorphism (Grubenmann); he considers that not only the garnet, but even the hypersthene, was produced in these circumstances. This does not accord with the obvious and almost unmodified igneous character of many of the rocks, and the present writer considers that the hypersthene at least is essentially a normal product of crystallization from the magmas, and that at least much of the garnet arose in this way. Garnet is now well-known to be a product of crystallization of many igneous rocks,⁴ and Stillwell himself describes,⁵ from certain rocks in Adelie Land closely analogous to the Charnockite Series, the case of a garnet mass which occurs graphically intergrown with quartz in pegmatite cutting a granodiorite gneiss free from garnets.

¹ Op. cit., p. 196. See also Fermor below, p. 490.

² See also Fermor on the ancient garnetiferous rocks of India, below, p. 490.

³ "Metamorphic Rocks of Adelie Land": *Rep. Aust. Ant. Exped.*, vol. iii, 1918, pt. i, p. 13. See also below, p. 489.

⁴ In this connection it may be noted that Dr. J. W. Evans has recently postulated the formation of garnets, together with certain other minerals of small molecular volumes, in magmas crystallizing under conditions of high pressures and comparatively low temperatures. "The Origin of the Alkali Igneous Rocks": *GEOL. MAG.*, Vol. LVII, 1920, p. 559. See also note below, p. 491, on garnets and "piezocrystallization".

⁵ Op. cit., p. 197.

Finally, it should be noticed that effusive rocks corresponding to the older and more important members of the group, such as the Charnockite Series and associated rocks, are not known, and also that the rocks of most of the magnesian provinces have been invaded by intrusions of very different composition, namely nepheline-syenites and associated rocks belonging to the Alkaline Series; as examples of these last may be given the nepheline-syenites of the Los Islands (West Africa),¹ the nepheline-syenites of India,² and the alkaline rocks of Scandinavia.³

The present writer recognizes that the Magnesian Group of rocks is not sharply divided from the rocks relatively poor in magnesium, any more than the alkaline, calc-alkaline, spilitic, and other petrographic suites are sharply divided from each other; most of these suites, in fact, either overlap or are indistinguishable at their acid and basic ends respectively, and it is, moreover, not always possible to distinguish between their intermediate members. Nevertheless, the conception of these suites has so far served a very useful purpose in petrography.

III. THE MAGNESIAN PROVINCES.

Reference has already been made to two examples of Magnesian Provinces, but there is reason to believe that similar Provinces exist also in the ten additional areas listed below; the rocks of the Group, however, appear to be developed to a variable extent in the different Provinces, and subsequent investigation may necessitate modification or extension of the list.

1. Ekersund, Soggendal, and Bergen districts in western and south-western Norway.⁴
2. Saxony and neighbouring areas, from which "pyroxene-granulites" and "pyroxene-gneisses" have frequently been described by earlier writers.⁵
3. Ural Mountains.⁶ (The rocks of this area, although resembling those of the other areas in many respects, generally carry augite instead of hypersthene.)
4. Southern India.⁷
5. West Africa.⁸
6. Eastern part of Ellesmere Land and Prudhoe Land.⁹

¹ Lacroix, *op. cit.*, 1911.

² *Mem. Geol. Surv. India*, vol. xxx, 1900, pt. ii.

³ Daly has commented upon the association of anorthositic and syenitic types both in the Adirondacks and in Western Norway. See *Igneous Rocks and their Origin*, 1914, p. 54.

⁴ C. F. Kolderup, *Berg. Mus. Aarb.*, 1896, No. V; also 1903, No. 12.

⁵ Rosenbusch, *Elemente der Gesteinslehre*, 1910, p. 187.

⁶ See H. S. Washington, "The Charnockite Series of Igneous Rocks": *Amer. Journ. Sci.*, 1916, p. 323. Also J. P. Iddings, *Igneous Rocks*, vol. ii, 1913, p. 511.

⁷ *Memoirs Geol. Surv. India*.

⁸ See above, p. 486.

⁹ C. Bugge, *Rep. 2nd Fram Exped.*, No. 22, 1910.

7. Haliburton and Bancroft Areas, Canada.¹
8. The Cortlandt Area, New York.²
9. The Blue Ridge, Virginia.³
10. State of Bahia, Brazil.⁴
11. Southern Eyre Peninsula, Australia.⁵
12. Adelie Land, Antarctica.⁶

It may be mentioned at this point that the North-West Highlands of Scotland,⁷ although lacking in typical development of the rocks of the Magnesian Group, is nevertheless related to many of the above areas in several important respects, particularly in the prevalence of amphibolites of various kinds.

IV. AGE OF THE MAGNESIAN GROUP.

It will at once be noticed that the areas given in the preceding paragraph include the more important known outcrops of pre-Cambrian igneous and metamorphic rocks, and attention may here be drawn to the remarkable lithological similarity of the pre-Cambrian terranes, a similarity which has already been noticed by several writers. Thus it may reasonably be concluded, in spite of the abundance of pre-Cambrian granitic rocks, that rocks of the Magnesian Group were of much greater importance in pre-Cambrian than in later times. This conclusion receives support from Daly's investigation into the relative abundance of and the time relations of the different families of igneous rocks;⁸ and from his table⁹ of the order of eruption of igneous rocks in different parts of the world it is obvious that rocks relatively rich in magnesium were intruded more frequently and bulked more largely in pre-Cambrian than in later periods.

V. ORIGIN OF THE MAGNESIAN GROUP.

Whatever cosmic hypothesis be adopted there is good reason to suppose that at a very early stage in the earth's geological history what is now known as the "crust" underwent a certain amount of differentiation leading to a density stratification. Moreover, in view of this early differentiation, the crust may be regarded¹⁰ as consisting

¹ J. P. Iddings, *Igneous Rocks*, vol. ii, 1913, p. 358.

² G. S. Rogers, *Ann. N. Y. Ac. Sci.*, xxi, 1911, p. 11.

³ Watson, *Bull. Geol. Soc. Amer.*, 1915.

⁴ See H. S. Washington, *op. cit. supra*.

⁵ C. E. Tilley, "The Granite-Gneisses of Southern Eyre Peninsula (South Australia) and their Associated Amphibolites": *Q.J.G.S.*, vol. lxxvii, 1921, p. 75.

⁶ F. L. Stillwell, "The Metamorphic Rocks of Adelie Land": *Rep. Aust. Ant. Exped.*, vol. iii, pt. i, 1918.

⁷ "The North-Western Highlands of Scotland": *Mem. Geol. Surv. Great Britain*, 1907.

⁸ *Igneous Rocks and their Origin*, 1914, p. 55.

⁹ *Op. cit.*, p. 469.

¹⁰ See Daly, *Igneous Rocks and their Origin*, 1914, p. 171.

of the following three shells which underlie, in downward succession, a discontinuous sedimentary shell :—

1. Granitic shell.
2. Transitional shell.
3. Basaltic shell.

Finally, as has been suggested by several authors¹ from consideration of the composition of meteorites, it is highly probable that the basaltic shell is underlain by a peridotite shell. If any such view be accepted, the known restriction of the majority of the magnesian rocks to the older parts of the earth's crust and to very early times receives some explanation ; in the first place, the deep-seated, highly magnesian magma of the lowest shell would be less likely to reach the higher parts of the crust than the overlying less magnesian rocks ; secondly, in the course of time these eruptions would get less and less chance of reaching higher levels, both because the solid crust would probably be increasing in thickness and because, with continued density stratification, the magnesian magmas would become more and more inaccessible ; and thirdly, the rocks once situated at a great depth would now be exposed at the surface only in those areas, such as Southern India² for example, in which uplift and progressive denudation have proceeded more or less uninterruptedly over a very long period of time. These ancient magnesian intrusives were frequently of very great size, and in this connection Holland has observed³ : " There is a strong probability that the magmas tapped in earlier geological periods were larger than those which gave rise to eruptions after the earth's crust had advanced in physical differentiation." The great variation in acidity shown by some members of the Magnesian Group may be explained by intermixture of the magnesian magma with varying amounts of the overlying magmas. That this intermixture would often be considerable may be assumed from the extraordinary development of igneous activity of all kinds in earlier periods of the earth's history.

Fermor,⁴ in an attempt to explain the common occurrence of garnet in the ancient rocks of India, and noting that the formation of this mineral in a rock is accompanied by a reduction in volume, came to the conclusion that the garnetiferous rocks originate in a relatively basic "infra-plutonic zone" of great depth and unusually high pressure.⁵ He states,⁶ moreover :—

¹ Daly, *op. cit.* Also L. L. Fermor, *Rec. Geol. Surv. India*, vol. xliii, 1913, p. 41.

² T. H. Holland, "The Charnockite Series": *Mem. Geol. Surv. India*, xxviii, 1900, p. 196.

³ *Op. cit.*

⁴ "Preliminary Note on Garnet as a Geological Barometer and on an Infra-plutonic Zone in the Earth's Crust": *Rec. Geol. Surv. India*, vol. xliii, 1913, p. 41.

⁵ Cf. also Dr. J. W. Evans ; see footnote on p. 487 above.

⁶ *Id.*, p. 44.

A release of pressure over any given portion of the infra-plutonic shell would allow the liquefaction of that portion of the shell under the high temperatures prevalent; such liquid rock, on being intruded into the higher portions of the earth's crust, would then solidify under less pressure as a plutonic rock. But in these circumstances, doubtless comparatively rare, in which the isogeotherms are lowered more rapidly than the pressure, it can easily be imagined that the rock would be able to crystallize in its infra-plutonic form, and then, by subsequent earth movements and denudation, be exposed at the surface.¹

Stillwell, however, in opposition to this view, states² that "the 'infra-plutonic zone' is indistinguishable from a metamorphic zone defined by the particular set of conditions", and he endeavours to show, moreover, that the garnets, the granularity,³ and, in fact, all the peculiar features of these rocks, are due to recrystallization in the solid state. In extension of this idea, he even argues⁴ that the following hypotheses, "founded on the transition between two rock types in metamorphic areas", might be explained "on the hypothesis of metamorphic diffusion", which he also regards as operating in the solid state:—

1. Intermingling of basic magmas with acid magma.
2. Differentiation of an intermediate magma into a relatively basic portion and a relatively acid portion.
3. Local melting or refusion in situ.
4. Gradual assimilation of pre-existing basic sediments by invading granite or gneiss.

It would indeed be strange if these ancient rocks had not suffered some metamorphism at least, but the evidence brought forward to show that metamorphic diffusion in the solid state is capable of producing such remarkable changes in the character of the rocks is far from being convincing.

Dr. J. W. Evans considers the presence of abundant hypersthene in charnockitic rocks as due to the influence of excess alumina, which he regards as having been derived by the absorption of aluminous sediments.⁵ So far there does not appear to be very much direct evidence in support of this theory in the various areas considered in this paper; in one of these areas, at least, namely the

¹ See also Holland on garnets in ancient rocks of Southern India, above, p. 485. Moreover, E. Weinschenk has brought forward evidence to show that the garnets, as well as the granularity, of the central granitic gneisses of the Alps may be regarded as having been produced during the crystallization of a viscous magma under the operation of a powerful directed pressure ("piezo-crystallization"), and not by later metamorphism. *Cong. Geol. Inter., C.R.*, viii, 1900, p. 326.

² Op. cit. supra, p. 196.

³ Granularity cannot necessarily be regarded as evidence of metamorphism; many igneous rocks are known to possess well-developed granular texture as a result of disturbance of some kind during crystallization. See Weinschenk *re* "piezo-crystallization", op. cit. supra, and also F. Dacey, "The Norite of Sierra Leone": *Proc. Geol. Soc.*, 1921, p. 103.

⁴ Op. cit., p. 121.

⁵ *Abs. Proc. Geol. Soc.*, 1921, p. 46.

Southern Eyre Peninsula, the theory has been held to be inapplicable.¹

VI. RELATION OF THE MAGNESIAN GROUP OF IGNEOUS ROCKS TO THE ALKALINE, CALC-ALKALINE, AND OTHER SERIES OF ROCKS.

A number of petrographic suites and series are already more or less well-known, and an attempt will be made in the following paragraphs to show what relation they bear to the Magnesian Group of rocks.

The series of rocks which most closely approaches the Magnesian Group is the Charnockite-Anorthosite Series proposed by Rosenbusch;² this series is said to contain many intermediate stages between the acid charnockite and the basic anorthosite, and also to possess peridotite and pyroxenic end-members. It should be noted, however, that many anorthosite masses contain only a small proportion of rocks rich in magnesium. The series is much more frequently found in association with the Calc-Alkaline Series than with the Alkaline, but it nevertheless differs considerably from the Calc-Alkaline Series in chemical composition and in rock types. Rosenbusch attempts to compare the chemical characteristics of the three series by taking four analyses from each, ranging through acid to basic types; the value of this comparison, however, is reduced by the fact that so few analyses are chosen while each series exhibits so many varieties, and more especially by the fact that the four analyses representing any one series are not of rocks of any one locality, or even of one continent. It is sufficiently evident, however, that the three series coincide at their acid and basic extremes, shown, for example, in that they all pass with decreasing silica into peridotites and pyroxenites. It is interesting to note that Rosenbusch has here made the term "charnockite" of general application, in spite of the fact that Holland emphatically declared³ that it ought not to be used outside India; if the term had not been so extended, however, a new term would have been necessary for general application to those groups of rocks, now known in many parts of the world, that closely resemble the Charnockite Series of India in all essential respects. Moreover, since the term was extended by Holland himself from the rock-name Charnockite to the name of the whole series, it is only logical to extend it to similar series elsewhere.

The Magnesian Group embodies the greater part of the Charnockite-Anorthosite Series, and includes also the highly magnesian rocks commonly associated with this Series. It is at present uncertain, however, where a distinction may be drawn

¹ C. E. Tilley, "The Granite Gneisses of Southern Eyre Peninsula (South Australia) and their Associated Amphibolites": *Q.J.G.S.*, vol. lxxvii, 1921, p. 75.

² *Elemente der Gesteinslehre*, 1910, p. 187.

³ "The Charnockite Series": *Mem. Geol. Surv. India*, vol. xxviii, 1900, p. 131.

between rocks of the Magnesian Group and the basic members of the Alkaline and Calc-alkaline Series; it is obvious that strong resemblances exist amongst these rocks. The Charnockite-Anorthosite Series and associated rocks, forming the most important members of the Group, are for the most part of pre-Cambrian age, whereas the other series referred to include types that are considerably younger.

A careful comparison of the chemical and mineralogical features of the three series as they are represented in West Africa has been made by Lacroix.¹ He has shown that the rocks of both the Charnockite-Anorthosite Series and the Calc-Alkaline Series are rich in magnesium and also in hypersthene, besides containing variable amounts of the magnesia-pyroxene.

The Spilitic Suite, proposed by Dewey and Flett,² is distinguished from both the Alkaline and the Calc-Alkaline Suites mainly by abundance of soda-feldspars and by association with special contemporaneous geographical conditions; in the opinion of several later writers,³ however, the Spilitic Suite is essentially a modification of the Calc-Alkaline Suite. Accordingly, the remarks already made as to the relation of the Alkaline and Calc-Alkaline Series to the Magnesian Group may be applied also to the Spilitic Suite.

Again, Wolff⁴ has suggested that certain basalts and basaltic rocks should be grouped together under the term "Arctic Tribe", and he has further proposed to include the Charnockite Series in this group. Washington,⁵ however, in a careful discussion of the Charnockite Series of India and a comparison of these rocks with analogous types of other regions, shows that the charnockitic rocks are clearly distinguishable from the ordinary basaltic or gabbroic rocks.

In conclusion, it may be mentioned that the conception of the Magnesian Group of Igneous Rocks is based on evidence that increases with our growing knowledge of the older parts of the earth's crust, and it is accordingly now put forward in the hope that it expresses a principle which may possibly be of some slight assistance in the general problem of the origin and relations of igneous rocks.

¹ "Les Syénites Nepheliniques de l'Archipel de Los": *Nouv. Arch. du Mus. d'Hist. Nat., Paris*, 5me Série, Tome 3, 1911, p. 108.

² "Some British Pillow-Lavas and Associated Rocks": *GEOL. MAG.*, 1911.

³ See R. A. Daly, *Igneous Rocks and their Origin*, 1914, p. 340.

⁴ F. v. Wolff, *Vulkanismus*, i, 1914, p. 153.

⁵ "The Charnockite Series of Igneous Rocks": *Amer. Journ. Sci.*, 1916, p. 323.

Some Points in Petrographic Nomenclature.

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DR. ARTHUR HOLMES has laid all petrographers under a debt of gratitude for his *Nomenclature of Petrology*, which worthily succeeds and replaces Löwinson-Lessing's *Lexique Pétrographique*. It represents an enormous amount of patient labour, and will provide an indispensable instrument of petrographic research. Its perusal has led the writer to consider several points in modern petrographic nomenclature which seem to need further discussion.

There is no need to labour the extreme complexity, unevenness, and confusion of present-day petrological nomenclature. Dr. Holmes illustrates it in his Introduction by compiling a list of no fewer than twenty-two different principles and characters upon which names have been based. This state of affairs is attributed by him to two causes: the natural tendency for the meaning of terms to expand and assume a wider connotation than originally intended; and the lack of a generally accepted classification. The first cause, as is shown by Holmes, really depends on the second; since meanings inevitably expand and wander unless the terms are restrained within the bounds of a sufficiently rigid framework of classification. The question of classification is therefore at the root of our nomenclatorial difficulties; and agreement upon a classification by petrographers, or the enforcement of a classification through the influence of a sufficiently powerful and inspiring teacher, especially in the case of igneous rocks, seems to be a pre-requisite to the successful reform of the nomenclature.

While not wishing to enter upon the extensive and involved subject of classification, it is desirable to remark that it is impossible for petrographers to wait until a genetic scheme of classification is evolved, particularly for igneous rocks. Furthermore, if and when a genetic classification is developed which commands general assent, it is extremely unlikely that it will lend itself to the detailed quantitative treatment that is so necessary for the purposes of petrographical research. In the meantime a grouping of rocks based on empirical characters susceptible to quantitative subdivision is urgently needed. Recent essays at classification have attempted to supply this need, but none have yet won general agreement amongst petrographers. There will be purists who will object that such groupings of rocks are not classifications at all, but indexes. But so long as we have an instrument that will enable us to describe and compare rocks in an exact and detailed manner, we shall be indifferent as to whether it is called a classification, a grouping, or even an index. Genetic classification will come in due time; but it will be broad-based upon the exact data provided by the quantitative instrument.

Considerable outcry has been made in the past by a conservative school of petrographers against the supposed enormous increase in the number of rock names, many of which are regarded by them as unnecessary. Yet, counting the names given in Holmes' glossary, dating up to 1920, we find that only 428 igneous rocks have separate names (excluding compound terms built up with mineral qualifiers, which, however, do not figure in the list). Some of these are nearly or quite obsolete; others are redundant, or cover but a minute portion of the petrographical field, or depend for their value on trivial differences that would not now be recognized as suitable bases for nomenclature. A great many of these names would certainly be discarded upon a critical revision. Probably less than half of the igneous rock names, or say about 200, are used at all frequently or with close definition, and are thus woven into the living texture of petrological science. Similarly there are only 137 sedimentary and 104 metamorphic rock names, which are subject to the same considerations as are made in the case of igneous rocks.

We may draw the conclusion that there are not too many rock names; on the contrary, there are ridiculously few, especially when the subject is compared with sister natural history sciences. There are certainly insufficient names to cover the enormous field of rocks at all adequately, and petrography thus suffers from a deficiency rather than a plethora of names. There are insufficient terms to indicate what are often considerable degrees of difference in rocks. Moreover, the terms in use are unequally distributed over the petrographical field; in common types of rocks a great range of difference may be covered by single names like andesite or basalt, whereas in a single small restricted group, as in some alkalic families, there may be a superabundance of names for closely related and essentially identical types. The terms andesite and basalt, especially, are greatly overworked, a circumstance that results in confusion in several fields of petrological research, notably that of petrographic provinces.

Dr. Holmes notes some of the disadvantages of the prevalent fashion of basing new rock names upon geographical terms. This method certainly brings about some ugly and cacophonous results, many petrographers having apparently not considered the question of euphony in naming their rocks. It is natural to prefer riebeckite-aegirine-granite to *fasitibikite*; and all petrographers will approve of the condemnation of such monstrosities as *kauaiite*, *anabohitsite*, and others that could be mentioned. Dr. Holmes seems to prefer the alternative method of prefixing a locality name to well-known petrographical terms, on the model of Markle basalt, Ponza trachyte, etc.; or using compound mineralogical prefixes in the same way. He states that names such as hornblende-biotite-granite are self-explanatory; but they are only so if the content of the rock term itself is well understood. The term *granite* in itself is no more self-explanatory than *bandaite* or *marloesite*;

and if the term *bandaite*, for example, is as well defined and understood as granite, the compound orthoclase-olivine-bandaite becomes as self-explanatory as hornblende-biotite-granite.

It is impossible to discuss the reform of petrographical nomenclature, in igneous rocks at any rate, apart from the consideration of the need for quantitative classification, preferably upon a mineralogical basis. Only when this is established will it be possible to make a serious attempt to systematize nomenclature. It may then be worth while to consider new prefixes and suffixes to be added to the roots at present in use, or whether it would be preferable to make a clean sweep, and begin *de novo* with a brand-new scheme of nomenclature. Only in relation to an exact scheme of classification will it be possible to discuss what amount of difference from already described and named types would justify a new name being given. In the absence of an accepted framework of classification, petrographers are justified in coining new names for rocks which, in their judgment, differ sufficiently from already recognized types for a new name to be of value; and when they consider the ascription of a divergent rock to a known class as a restriction of the usefulness of the latter by unduly widening its meaning.

A perusal of Dr. Holmes' glossary suggests many interesting points of nomenclature of which it will only be possible to discuss a few in this paper. It may be remarked in passing that Dr. Holmes' definitions are admirably concise and well expressed. He has rightly chosen to record the customary and current meanings of the terms, and has abstained from critical comment, which could only have been satisfactorily conducted from the standpoint of classification, and would have overstepped the intention of the book.

The abundance of andesites and basalts, and their importance in petrogenetic and distributional studies, renders their exact definition and difference a question of considerable magnitude. Dr. Holmes states (p. 32) that the modern primary distinction between andesite and basalt does not depend on the absence or presence of olivine, or on the relative proportions of felsic to mafic minerals (though each of these criteria have been applied in the past), but on the composition of the plagioclase. As bearing on this statement it is noteworthy that in the last comprehensive work on igneous rock classification¹, the main distinction between andesite and basalt is based on the proportions of felsic to mafic minerals, the true basalts (p. 197) having equal or nearly equal amounts of each, the andesites being preponderantly felsic. It is recognized that the felspar in andesites is *usually* andesine or oligoclase, and that in basalts labradorite or even more calcic varieties; nevertheless, labradorite-andesites are described as well as oligoclase-basalts. When containing olivine labradorite-andesites have often been described as

¹ Iddings, *Igneous Rocks*, vol. ii, 1913.

olivine-basalts; when free from olivine they have been designated either as basalt, felspar-basalt (Fr. labradorite), or, as frequently, andesite.

The reasonableness of Iddings' position is demonstrated by a study of the quantitative mineral composition of average andesite and average basalt. Professor R. A. Daly has computed the average andesite and basalt from the analyses of rocks named as such in Osann's lists.¹ These averages are set out for comparison in Table I, 1, 2.

TABLE I.
CHEMICAL COMPOSITION OF AVERAGE ANDESITE AND BASALTS.

	1.	2.	3.
SiO ₂	59.59	49.06	47.20
TiO ₂	.77	1.36	2.44
Al ₂ O ₃	17.31	15.70	14.93
Fe ₂ O ₃	3.33	5.38	4.11
FeO	3.13	6.37	8.23
MnO	.18	.31	.25
MgO	2.75	6.17	6.92
CaO	5.80	8.95	10.02
Na ₂ O	3.58	3.11	2.71
K ₂ O	2.04	1.52	.84
H ₂ O	1.26	1.62	2.13
P ₂ O ₅	.26	.45	.33
	100.00	100.00	100.11

- 1.—Daly's average andesite, *tonalose*, 'II.4.'3.4. *Igneous Rocks and their Origin*, 1914, p. 26. Anal. No. 46.
- 2.—Daly's average basalt, *andose-camptonose*, (II) III.5.3.'4. Op. cit., p. 27, Anal. No. 53.
- 3.—Average plateau-basalt, *auvergnose*, III.5.(3) 4.4'. Computed from thirty-seven analyses of plateau-basalts from the Brito-Arctic region (Siberia, North Russia, Franz Josef Land, Spitsbergen, Greenland, Jan Mayen, Iceland, Faroe Islands, and the Inner Hebrides); the Columbia and Snake River plains, Western United States; and the Carboniferous Clyde plateau, Midland Valley of Scotland. Analyses obtained from H. S. Washington's "Analyses of Igneous Rocks, 1883-1913", Prof. Paper 99, *U.S.G.S.*, 1917; A. Holmes, "The Basaltic Rocks of the Arctic Region", *Mineral. Mag.*, xviii, 1918, 180-223; and H. G. Backlund, "On the Eastern Part of the Arctic Basalt Plateau," *Acta Academiae Aboensis, Math. et Phys.*, i, 1920, 1-53.

These computations are not ideal, for there can hardly be any doubt but that each of them covers too wide a range of rocks. The andesite average contains rocks which to-day would be designated as dacite, latite, perhaps even trachyte. The basalt average no doubt contains rocks which would nowadays be called andesite; but this, perhaps, is partly compensated for by the inclusion of rocks such as limburgite, trachydolerite, basanite, etc., which diverge in various directions from true basalt. Daly's average andesite is thus probably more silicic and alkalic than the real average andesite; while the average basalt is probably defective in the same direction, although to a less extent than the andesite. However, these

¹ *Igneous Rocks and their Origin*, 1914, pp. 26-7.

analyses, when calculated into the norms, which closely correspond to the modes in essentials, illustrate well the fundamental differences of andesite and basalt. Andesite is a dofelsic type, basalt mafelsic, more than five-eighths of the total mineral content in andesite belonging to the felsic group of minerals, and less than five-eighths in basalts. This fact is illustrated by the norms (tabulated in Table II), the average andesite falling into *tonalose*, II.4.3.4. and the average basalt into *camptonose* III.5.3.4.

TABLE II.
NORMS OF AVERAGE ANDESITE AND BASALT.

		1.	2.	3.
S	Quartz .	14.70	—	—
	Orthoclase .	11.68	8.90	5.00
	Albite .	30.39	26.20	23.06
	Anorthite .	25.31	24.46	25.85
F	Diopside .	1.77	13.87	17.70
	Hypersthene .	8.04	11.86	10.17
	Olivine .	—	1.87	4.85
	Magnetite .	4.87	7.89	6.03
	Ilmenite .	1.52	2.58	4.56
	Apatite .	.51	1.01	.67
	Ratio S/F	4.89	1.53	1.22

The norms are arranged in the same order as the analyses in Table I.

No petrographer has any hesitation in classing the dense, heavy, generally olivine-bearing rocks of the great basalt floods (Brito-Arctic region, Deccan, Western America, etc.) with the true basalts; the types about which there is doubt as to their position, labradorite-andesite, bandaite, andesitic basalt, basaltic andesite, olivine-andesite, olivine-free basalt, felspar-basalt, and the like, are mostly to be found in andesitic provinces. Daly's average basalt includes rocks of both types, and is therefore both more felsic, and the felspar more alkalic, than in true basalts. An average computed from the analyses of basalts belonging to the plateau-basalt regions of the world should be distinctly more basic than Daly's average basalt. This was found to be the case on computing the average of thirty-seven plateau-basalts (Table I, 3) from the Brito-Arctic region, the Columbia and Snake River plains of Western America, and the Carboniferous Clyde plateau of the Midland Valley of Scotland. This average falls into the subrang *auvergnose*, III, 5.4.4-5, and its norm is stated for comparison in Table II, 3.

The general increase in basicity (maficity) from andesite to plateau-basalt is well shown by the diminution of the S/F ratio. The border-line between andesite and basalt should be at the ratio S/F 1.67, if the distinction be made on the basis of the ratio of felsic to mafic constituents. In this connexion it should be pointed out that the norm ratio is always higher than the mode ratio, since the method of computing the norm always ensures the

maximum possible amount of salic constituents. In considering the norms another point of interest bearing on the question of classification is that the normative plagioclase remains practically of the same chemical composition throughout the series, the basaltic felspar being only slightly more calcic than andesitic. While it is not urged that the average modal plagioclases of andesites and basalts are of nearly the same composition, the above fact certainly seems to tell against the distinction between andesite and basalt being based on the nature of the felspar only.

Another interesting question concerns the nomenclature of the so-called hypabyssal rocks. Some authorities regard the minor intrusions or hypabyssal rocks as a classificatory division co-ordinate in importance with the plutonic and the volcanic. Others regard them merely as textural modifications of plutonic types consequent upon slightly different cooling histories. It is probably best to treat these rocks as textural modifications both of plutonic and volcanic types, having chemical and mineral compositions corresponding with one or the other. This implies that plutonic and volcanic rocks do not exactly correspond in chemical and mineral characters; that is, the average andesite, for example, has not the same chemical and mineral composition as the average diorite, or the average basalt that of the average gabbro. This has been demonstrated by Daly in his studies of average igneous rock types.¹ The exact differences need not now be dwelt upon. It follows, however, that some hypabyssal rocks, porphyries for example, would best be described as andesite-porphyries, others as diorite-porphyries, and so on. It is probably the subconscious and implicit recognition of this fact that has led to many terms in hypabyssal rock nomenclature gradually acquiring a textural significance, while still retaining a specific meaning. Aplite and pegmatite are outstanding examples of this extension of meaning. They have well understood specific meanings; when used alone they mean respectively granite-aplite and granite-pegmatite. But syenite-aplite, gabbro-pegmatite, and like terms, are equally well understood, in which the terms aplite and pegmatite have a textural meaning. It may well be questioned whether such an extension of meaning is not the inevitable end of all hypabyssal rock terms if these types be regarded, not as co-ordinate in classificatory value with plutonic and volcanic rocks, but merely as textural satellites of either group. The textural signification of aplite, pegmatite, and porphyry, may apply to the whole chemical and mineralogical range of igneous rocks. Aplites and pegmatites, however, are always satellitic to plutonic types; porphyries may be attached to either plutonic or volcanic types. Other hypabyssal terms, if used with textural significations, may, however, not apply to the whole range of igneous rocks. *Felsitic*, *keratophyric*, and *orthophyric* apply only toward the "acid" end of the igneous series; *bostonitic* and *tinguaitic*

¹ *Igneous Rocks and their Origin*, 1914, Table II, p. 19.

apply to intermediate felspathic and felspathoidal types; and *doleritic* applies to the more "basic" types of igneous rocks corresponding in general chemical composition with gabbros and basalts.

With the above use of *porphyry* the term *porphyrite* ceases to have any significance. It has been used to indicate porphyritic hypabyssal rocks of andesitic or dioritic composition. The term has been so variously used that it would be better to drop it altogether, and to use diorite- or andesite-porphyry, in which the prefixes give the mineral composition, and "porphyry" the characteristic texture.

The terms *dolerite* and *doleritic* should always carry the connotation of ophitic texture. In some cases it may be difficult to distinguish between a coarse-grained basalt and a dolerite (Holmes, p. 83); but a coarse-grained basalt with its usual intergranular texture is quite different from the rock that it is customary to call dolerite, at least in Scotland. Moreover, ophitic texture is rare in the true effusive basalts, whereas it is very common in the intrusive dolerites even when these rocks are of similar grain-size to coarse basalts, or of even finer grain. Used by itself the term *dolerite* may be understood to carry the mineralogical implication of basic plagioclase, augite, and iron-ore, the rock corresponding in chemical and mineral composition to either gabbro or basalt, and as being characterized by ophitic texture. The average basalt is more "basic" (mafic) than the average gabbro; and corresponding variations are to be found in the dolerites, some of which are of gabbroid, others of basaltic composition. This use of the term would allow it to be also used, with a textural significance, for the hypabyssal equivalents of other "basic" plutonic and volcanic rocks. There is a real need for terms such as teschenite-dolerite, essexite-dolerite, and the like, for rock types quite common in Scotland and elsewhere, which can be given no more suitable names.

In connexion with *teschenite* it should be recognized that this term connotes more than "an alkali-rich variety of analcite-dolerite characterized by the presence of idiomorphic purple augite or aegirine-augite, and generally containing soda-amphiboles such as barkevikite" (Holmes, p. 224). Many of the rocks are quite as coarse as the average gabbro, and are free from doleritic characters such as ophitic texture. The term *teschenite* should denote analcite-gabbro, just as *thermalite* denotes nepheline-gabbro. The rocks of the smaller intrusions, and marginal modifications of the larger and coarser masses do, however, possess doleritic characters; in which case they are more correctly referred to as teschenite-dolerite or doleritic teschenite. The treatment of teschenite as analcite-gabbro has been tacitly adopted by Dr. A. Harker in the latest edition of his *Petrology for Students* (1919), where the rock is dealt with in the chapter devoted to gabbros, whereas in the previous edition it was described under the heading of dolerite. By

Iddings teschenite is treated as a plutonic rock, but is regarded as an analcitic variety of theralite, in which the analcite "may be altered nepheline".¹ This view is a survival from the period in which the analcite in this and in other rocks was thought to be of secondary origin. Nepheline does occur in some teschenites, and is often altered; but it does not alter into analcite. Analcite has been shown to be a primary constituent of teschenite, and many other analcitic igneous rocks; but owing to its aqueous constitution, and the consequent mobility and chemical activity of its solutions or magma, it is an extremely efficient agent of paulopost alteration in previously formed mineral constituents, with the result that analcite itself has been regarded as secondary. In other words the analcite is not due to the alteration of the other minerals, but the alteration is due to the analcite. If analcite be recognized as a primary mineral constituent in teschenite, this rock is as valid a rock species as theralite, and deserves equal recognition in a system.

We have no space in which to discuss the nomenclature of sedimentary and metamorphic rocks at any length. One point that struck the writer in reading Dr. Holmes' *Nomenclature of Petrology* was that the term *psammitic* was treated as exactly synonymous with *arenaceous*, also *pelitic* with *argillaceous* (p. 35), and *rudaceous* with *psephitic* (p. 202). It would appear consonant with current use, however, to restrict the terms of Latin derivation to sedimentary, and those of Greek derivation to metamorphic rocks. We do not speak of arenaceous gneiss but of psammitic gneiss; pelitic schist, in like manner, is regarded as a more felicitous term than argillaceous schist; whereas the adjective *psephitic* usefully describes the metamorphic rocks derived from the metamorphism of conglomerates, etc. The term *arenaceous* conveys (at least to the writer) a suggestion of past, present, or potential looseness of grain, whereas the corresponding less well-known Greek term does not carry this suggestion. Similarly *argillaceous* conveys a suggestion of softness, plasticity, and extremely fine grain, which is not so directly conveyed by *pelitic* except perhaps to Greek scholars. Hence it is suggested that the terms *psammitic* and *pelitic* might usefully be restricted to the hard metamorphic rocks which have been changed beyond the limits implied by the corresponding Latin terms.

Grabau's term *rudaceous*, applied to coarse detritus such as gravel, shingle, talus, and their compacted representatives, completes the trilogy of Latin adjectives for the principal gradings of sedimentary rocks. The term *psephitic* is not quite synonymous with *rudaceous* as it also conveys the suggestion of rounded pebbles. This sense is also seen in the use of the term *psephicity* by Mackie to indicate degrees of roundness in sand grains. But as during metamorphism angular fragments tend to become more or less rounded, the term *psephitic* will apply with considerable degree of exactitude to those

¹ *Igneous Rocks*, vol. ii, 1913, p. 248.

types formed by the metamorphism of rudaceous sedimentary rocks. The above suggested use of the terms *psephitic*, *psammitic*, and *pelitic*, has been adopted in many recent memoirs of the Geological Survey of the United Kingdom, especially those dealing with the gneisses and schists of the northern, north-western, and Grampian Highlands.

On a Mammoth Molar from North Woodchester, near Stroud.

By FRANK RAW, B.Sc., F.G.S.

(PLATE X.)

THE tooth, of which a photograph (half-size) is reproduced, was found during Easter, 1916, by the late Mr. W. Harrison, of Selly Oak, Birmingham, who kindly lent it to the writer. Though similar finds are fairly common, this tooth by its form is of rather special interest, and so the writer thinks merits description.

According to the note written down at the time it was received from Mr. Harrison, it was found "at North Woodchester, at the base of the hill that rises to Selsley Hill". This village is about $1\frac{3}{4}$ miles S.S.W. of Stroud, Gloucestershire, on the west side of the valley that runs here behind the edge of the Cotteswolds, of which Selsley Hill forms a part. North Woodchester lies along the road that runs west from the bottom of this valley (perhaps 150 feet O.D.), and rises to Selsley Hill (689 feet). The range in height of the village is from 200 feet O.D. to 300 feet O.D., and from the description of the site by Mrs. Harrison the writer judges the altitude of the find to be about 300 feet O.D.

The tooth was found in a gravel pit, the gravel consisting largely of Oolitic and Liassic debris. *Terebratula globata*, fragments of *Belemnites*, and *Ammonites serpentinus* were recognized by the writer among the material collected from it by Mr. Harrison. As North Woodchester, according to the Geological Map, lies on Upper Lias, it may be concluded that the deposit of gravel lies on this formation, whence was derived *Ammonites serpentinus* and probably the *Belemnites*. Selsley Hill is of Inferior Oolite, which also forms the high ground to the east and covers a large area to the north.

Mammoth remains seem fairly common in these gravels near Stroud. W. C. Lucy in 1869¹ records the occurrence of remains of the mammoth, woolly rhinoceros, reindeer, and bison (*Bos primigenius*) in Gannicox Pit, Stroud, as well as land and freshwater snails from lenticles of clay interstratified with the gravel. Mr. Edwin Witchell,² who had discovered these fossil shells, describes the gravels and their fossil contents, mentioning "fine tusks of the mammoth

¹ W. C. Lucy, "The gravels of the Severn, Avon, and Evenlode, and their extension over the Cotteswold Hills": *Proc. Cottes. Nat. F.C.*, vol. v, 1869.

² E. Witchell, *The Geology of Stroud*. Also *Stroud Nat. Hist. and Phil. Soc.*, 1876-8. *Proc. Cottes. Nat. F.C.*, vol. viii, 1883.

and teeth of the woolly rhinoceros and reindeer". He states that "there is an absence of marine or estuarine shells in these gravels", and that "it is therefore probable that the whole of these gravels are of fresh-water origin, and were the drifts and breakers of a lake which once occupied the valley of the Severn". The writer knows of no facts militating against this conclusion. Mr. L. Richardson,¹ in a report of a visit of the Cotteswold Club to the Gannicox and Cainscross gravel pits near Stroud, in the course of a useful summary of what was known of the fossil contents of the gravels, gives a list of thirteen species of land and freshwater shells obtained by Witchell from clayey seams in the gravels, not one of which is a marine species.

The assemblage of mammalia is of glacial character and points to a time near that of the "Würm" glaciation, the last of the major glaciations established by Penck and Brückner in the Alps, and coinciding with the formation of the "Newer Drift" of the North European plain. It was there that the mammoth was most numerous, though its remains are fairly common in deposits of the earlier "Riss" glaciation. Mammoth remains are also recorded from a considerable number of places in and around the Cotteswolds. It is generally agreed that there was no glaciation of the Cotteswolds, which were too high to be overflowed, but not high enough to nourish glaciers of their own, and the writer imagines that herds of mammoths roamed over the area, while the Welsh mountains, perhaps at that time higher relatively than now, owing to an uptilt of the country to the west, shed extensive glaciers across the estuary of the Severn, and by damming back the waters formed a lake, to the fluctuating levels of which the Cotteswold streams built deltas, but to quote Mr. Richardson,² "more work is necessary" (and the writer has done none) "before any suggestion of value can be made."

DESCRIPTION OF THE TOOTH.

The tooth measures 8 inches in length, by $4\frac{1}{2}$ inches deep, by $2\frac{3}{4}$ inches wide, the photograph being half natural size. In shape it closely resembles a yacht, the worn surface of the tooth corresponding to the deck of the ship; but the front of the yacht is seen in the posterior end of the tooth and vice versa.

The lateral aspect is about equally divided between the complexly folded broad crown and the narrower "keel", the depth of crown and keel being about equal to one another in the different parts of the length. The worn surface being oblique, one lateral aspect (the outer) has less crown than the other.

The superior aspect is entirely occupied with the grinding surface, which, though nearly flat, is obliquely concave. This measures $7\frac{1}{4}$ by $2\frac{3}{4}$ inches. All the tooth folds or "plates" that remain are worn, the keel being only 1 inch below the posterior border,

¹ L. Richardson, *Proc. Cottes. Nat. F.C.*, vol. xviii, 1914, pt. iii, p. 205.

² L. Richardson, "Excursion to Stroud": *Proc. Cottes. Nat. F.C.*, 1914, p. 205.

while in front the grinding surface cuts across the base of the crown, exhibiting the bottom of an enamel infold. Twelve plates are evidenced together with a talon behind, but it is impossible to say how many have been ground away entirely in front.

The curved shape of the base of the crown and its relative shallowness indicate that this is a *lower* molar, and since when looked at from above the plates run obliquely forward to the left, it is seen to belong to the *right* side of the mandible.

Posteriorly the crown narrows like the prow of a ship to a relatively fine edge, and thus gives *no* suggestion of pressure being exerted through a tooth following it in the jaw. This would indicate that it is the last tooth or third true molar. Its characters thus indicate an *ultimate right lower molar*.

For specific determination of such teeth reliance is placed on the form and spacing of the "plates" and the thickness and form of the enamel layers as seen in section on the grinding surface. In the Woodchester specimen the plates are closely spaced and the dentine and cement are in parallel bands and almost exactly equal to one another, but the posterior plates are drawn forward and constricted near their middle. The closeness of the plates is indicated by the length of tooth for a definite number of plates. There are ten complete folds in 5·75 to 6 inches or eight full size in 4·6 inches. The enamel is about ·06 in. thick, is crimped, and especially throughout the posterior half of the tooth forms compressed outfolds on the plates. These characters taken all together indicate *Elephas primigenius* or the *Mammoth*, though each of these characters could without doubt be matched among teeth ascribed to *Elephas antiquus*. According to Dr. Adams¹ the number of plates, not counting the talon or heel at each end in the last molars of the mammoth ranges from 18 or 19 to 27, the width from 2 to 4½ inches, the closeness of the plates from eight plates in 5 in. to the same number in 3·1 in. In our tooth the measures given above of width (2¾ in.), and closeness of plates (eight in 4·6 in.), fall well within this range. But as already noted detrition here is very far advanced, the remaining portion of the crown varying from 1 in. deep behind, through 2 in. at its deepest, to 0 in. in front and so the number of plates is quite unknown. And as the commonest number of plates in these teeth is probably 22 or 23, the plates at the anterior end which are worn right away to the base are the middle ones of the entire tooth. Thus the superior surface probably measured originally 14 in. or 15 in. by 2¾ in., while we may take the original depth of the crown as probably 4 in. or 4½ in. The animal was thus in advanced old age, and had worn away all but one-sixth or one-eighth of the volume of the crown of its last teeth.

Moreover, the occurrence of a continuous keel below the crown in place of a number of fangs seems to be characteristic of the last part

¹ A. Leith Adams, "British Fossil Elephants": *Palaeontographical Society*, 1877-81, p. 125.



Photo, F. Raw.

MOLAR OF MAMMOTH, NORTH WOODCHESTER, STROUD. $\frac{1}{2}$ size.

of the last tooth and part of the arrangement for pushing it up into a working position in the absence of pressure from behind. Mr. Adams (*loc. cit.*, p. 121), describing a much detrited last lower molar in the Woodwardian Museum, says: "The fangs had become consolidated into a ridge like the keel of a vessel"—an exactly similar condition to that here displayed. This character may thus be taken as confirming the conclusion otherwise arrived at that this is an ultimate molar. For a microscopic examination of the substance of the keel the writer is indebted to Mr. W. Courtney Lyne, who identifies it as dentine, which normally composes the fangs.

Compared with last lower molars of the mammoth described by Mr. Adams (*loc. cit.*), and with the fragments in the Birmingham University Geological Museum, this is rather a narrow tooth, but the measures of several narrower are given in the work referred to. On the other hand, judging by what remains, it would, when complete, be fully as long as the complete molars there described, but these from their very completeness are probably for the most part smaller than the average. It is, indeed, by no means as large in any dimension as they often attain.

The tooth is in a good state of preservation, the grinding surface, though much cracked, preserving the original relief and a fair degree of polish on the enamel. But at the sides of the crown the cement has in places fallen away as has also dentine from the keel. It exhibits no effects of water-wear and so cannot have been carried by water far from the mandible and the skull. There is every probability, therefore, of more mammoth remains having been entombed in the neighbouring gravel.

The tooth is in the possession of Mr. Harrison's widow, to whom the writer is deeply indebted for an extended loan of the specimen and for information regarding the position of the find.

EXPLANATION OF PLATE X.

Photograph of ultimate right lower Molar of Mammoth found at North Woodchester, near Stroud, by the late Mr. W. Harrison, of Selly Oak, Birmingham, Easter, 1916. Photo—half natural size.

The Primary Zones of Cornish Lodes

By E. H. DAVISON, B.Sc., F.G.S.

DURING the last two and a half years I have been engaged in the study of the Cornish Veinstones in the field and in the laboratory by microscopic and other methods, and have come to the following conclusions:—

That, as recognized by many observers, the primary minerals of Cornish lodes occur in zones which change their character in depth; thus copper minerals give place to cassiterite on passing down the lode and chlorite gives place to tourmaline.

From observations on over 150 lodes in more than 100 different mines, taken on the spot or abstracted from old records, in and

around the Carn Menellis granite mass, from Camborne and Redruth on the north to Falmouth and Helston on the south, it appears that the boundaries of the various zones can be determined within reasonable limits. I felt some hesitation at trusting to old records of depth which were sometimes measured on the underlie of the lode and sometimes vertically, but on determining the average depth below surface at which predominant copper gives place to copper with tin, from old and recent records, in the neighbouring parishes of Redruth and Camborne taken separately (the two areas having a similar geological character), I found that the two results differed by less than 15 fathoms, which shows that the estimates were sufficiently accurate to justify the conclusions drawn.

The general character of the zoning as regards tin and copper has been described by MacAlister,¹ but wolfram and arsenic are also to be considered, as they are important lode constituents. The general occurrence of the minerals is as follows:—

1. A zone situated some distance above the granite surface in the clay slate and often extending beyond the metamorphic aureole in which the metals silver, lead, and zinc are predominant. These metals arrived later than the tin or copper and often filled fissures belonging to a later period of earth movement, but they are also occasionally found in the uppermost parts of the tin-copper lodes, and this was probably still more often the case before the lodes were so extensively planed down by denudation.

2. A zone in which copper is the predominant metal comes next below the silver-lead zone. The copper zone passes downwards into the next zone at a depth which depends on the level of the granite surface.

In the neighbourhood of ridges or of “cupolas” on the granite surface the place of copper is usually taken by wolfram, and there is then a wolfram zone just above or just inside the surface of the granite mass.

3. A zone characterized by the occurrence of both tin and copper in fair proportions. In the proximity of “cupolas”, or ridges, this zone becomes in many instances a tin-wolfram zone.

4. A zone in which cassiterite is the predominant metallic mineral.

In no mine has the lower limit of this tin zone been actually reached, but evidence obtained in the mines sunk most deeply in the granite seems to indicate that there is a limit to its extension downwards. If the cassiterite does not actually die out, its grain tends to become so fine as to render profitable exploitation very difficult.

In the following notes on the various zones the general characters of the veinstones have been kept in view throughout; local exceptions occur, but only in a few instances.

¹ *Geological Survey Memoir*, Sheet 352, Camborne and Falmouth, 1906.

THE SILVER-LEAD ZONE.

The number of instances in which tin- or copper-bearing lodes pass upwards into lodes carrying lead and silver is too small to admit of any generalization. Silver and lead occurred with tin and copper in the Engine Lode, South Tresavean, silver with arsenic in the South Entral Lode, Dolcoath, and horn silver in the lode at North Dolcoath. Most of the lead-silver lodes have a north and south direction, and are of distinctly later date than the tin-copper lodes.

THE COPPER ZONE.

This zone is characterized by the predominance of copper minerals with mispickel as a frequently associated mineral. The copper occurs mainly as chalcopyrite, which seems to be the only original sulphide, the others present, such as bornite, erubescite, cuprite, native copper, and the oxidized compounds having been formed by its secondary alteration. Pyrite and some of the mispickel seem also to be of secondary origin.

Portreath.

Porkellis.



FIG. 1.—Sketch section to show relation of zones to granite surface.

The chief gangue minerals are quartz, chlorite, fluorspar, and muscovite; tourmaline is not usually an important component, but occurs locally in one or two districts.

The copper zone is in nearly every case restricted to the clay slate; its lower limit in the Camborne-Redruth district lies at an average depth of 100 fathoms, with a maximum of about 200 fathoms. As it is traced northwards away from the Carn Menellis granite mass, the base of the zone falls steadily (Fig. 1).

The position of the zone in other districts can be seen from the following table :—

District.	Depth of Base of Copper Zone in fathoms.		Position of area, relative to granite.
	Average.	Maximum.	
Camborne and Redruth	100	200	On flank of granite mass.
Gwennap	150	plus 300	Away from granite mass.
Wendron	No Copper Zone.		Heart of granite mass.
Crowan	50		Flank of granite mass.
Gwincar	150	200	Away from granite mass but in area of contact altered slate.
St. Day	60		Flank of granite mass.

The close connexion between the predominance of copper and the granite is shown by instances of lodes passing from slate to granite into slate again, the copper always being predominant in the slate and the tin in the granite.

THE WOLFRAM ZONE.

As mentioned above, the place of copper is sometimes taken by wolfram, which occupies a similar relative position in the lode. It is probably not accidental that all the wolfram-producing lodes are found in the neighbourhood of ridges or minor domes ("cupolas") of the granite. In such position the wolfram may be found either in the clay slate, as at Castle-an-Dinas and Killifreth, or just inside the granite, as at Hemerdon and Kit Hill. It may also occur in lodes passing from the slate into the granite, as in the case at Tin Croft Mine, Roger's Lode, East Pool Mine, etc. The lodes are of coarser texture than usual, and sometimes show a pegmatite-like structure, the chief minerals being quartz, chlorite, mispickel, wolfram, and cassiterite; tourmaline is not usually present in large quantities, fluorspar is often present, and molybdenite, stannine, and pyrite are occasional constituents. The wolfram content decreases and the cassiterite increases as the lode is followed from the slate into the granite either in depth or horizontally.

THE COPPER-TIN ZONE.

In most cases the copper zone of a lode passes downwards into a zone in which the lode carries both copper and tin in fair proportions. This zone is perhaps more correctly described as a passage zone from the zone of predominant copper to that of predominant tin, but it is often so clearly marked and has produced so much ore in many mines, that its classification as a separate zone is perhaps justified.

In the various districts the position of the zone is as follows :—

<i>District.</i>	<i>Depth of Base of Cu Sn zones in Fathoms.</i>		<i>Position of Area.</i>
	<i>Average.</i>	<i>Maximum.</i>	
Camborne and Redruth	180	300	On flank of granite mass.
Gwennap	—	—	Away from granite mass.
Wendron	50	100	Heart of granite mass.
Crowan	150	—	Flank of granite mass.
Gwinear	200	—	In area of contact altered slate away from granite.
St. Day	150	—	Flank of granite mass.

The composition of the lode-stuff is similar to that of the copper-zone, but mispickel is more common, and tourmaline is present in greater proportion. The vein-stone generally appears under the microscope as well-crystallized, with quartz, chlorite, mica, tourmaline in well-formed blue and brown prisms, chalcopyrite,

mispickel, and cassiterite in large, well-formed crystals. The chalcopyrite and mispickel are seen to have crystallized after the cassiterite, which is often included in them. This type of veinstone is often a bright green colour in the hand specimen, and with a vughy texture; it is locally termed "peach". The number of lodes which pass downwards from a zone with predominant wolfram is small, as few wolfram lodes have been worked to any depth. The facts show, however, that wolfram dies out and cassiterite increases as the lode is followed into the granite and there is possibly a similar passage zone to that of the copper-tin lodes.

THE TIN ZONE.

In all the lodes the tendency is for the lode to become predominantly tin-bearing in depth. There is also a decided change in the character of the veinstones. The chlorite, so common a constituent in the upper zones, diminishes or disappears, and the type of veinstone locally termed "capel" is the usual one. This is a fine-grained blue veinstone composed of quartz crowded with microscopic needles of blue tourmaline, and often brecciated, the fragments consisting of capel containing fragments of cassiterite, and clear quartz, the cement being quartz, coarser tourmaline, and cassiterite which is more coarsely crystallized and of a paler colour than that in the capel.

There are only a few mines which have been worked to any great depth in the granite, and in consequence the facts on which conclusions might be based are scanty. There seems, however, to be a distinct indication that there is a limit in depth to the tin zone. In many instances the cassiterite not only decreases in amount, but also becomes of a decidedly finer grain, thus rendering the lodestuff less amenable to concentration by gravitational methods.

In reference to the fine grain of the cassiterite in some veinstones, both at moderate and considerable depths in the granite, I would refer to my paper read before the Royal Geological Society of Cornwall,¹ in which cassiterite is described as occurring in the form of minute inclusions in quartz, the grains being less than one micro-millimetre in diameter.

The extent of the zones described above varies very greatly at different points round the granite mass, and this variation has been attributed² to the variation in slope of the granite surface below the slate. Recent development of the mines has produced fresh evidence of the fact that the Carn Menellis mass slopes very gradually to the north below the clay-slate (Figs. 2, 3, and 4). The occurrence of a large inclusion of granite in the quartz-porphry ("elvan") dyke at Bridge, near Portreath, suggests that even so

¹ "On the Mode of Occurrence of Cassiterite in Cornish Veinstones, etc.": *Proc. Roy. Geol. Soc. Corn.*, 1919.

² MacAlister, *Geol. Surv. Mem.* Sheet 352, Camborne and Falmouth, 1906.

far to the north as that the granite is at no great distance below the surface, and there is every probability that the copper and tin zones occur at workable depths over a large area to the north of the present mines in the Camborne-Redruth district.

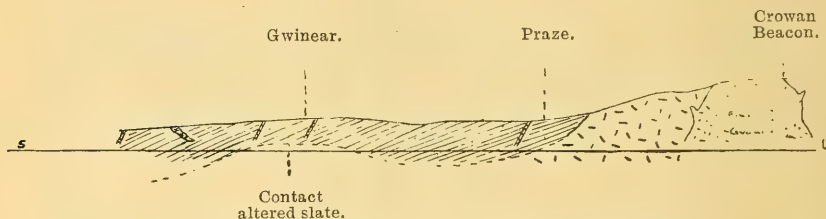


FIG. 2.—Sketch section from Crowan Beacon to Gwinear.

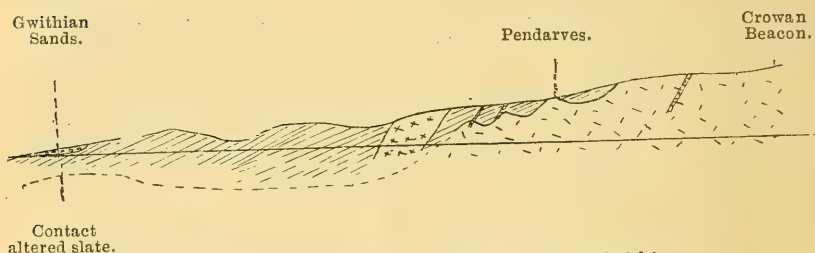


FIG. 3.—Sketch section from Crowan Beacon to Gwithian.

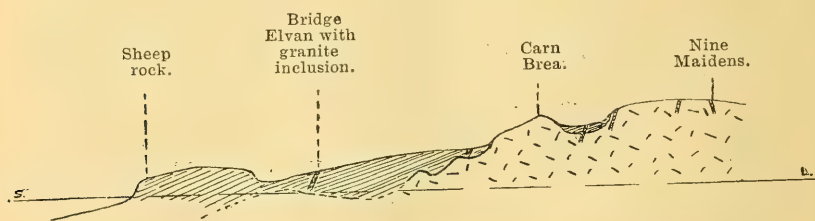


FIG. 4.—Sketch section from Nine Maidens to Portreath.

In addition to the vertical zones of the lodes described above, there is a variation in the lode contents along the strike. A lode is not usually of uniform value throughout its length, but the metallic minerals occur in "shoots" or "courses" which alternate along the lode with areas of low-grade ore of little or no economic value. These shoots are not usually vertical, but run diagonally down the lode and their exact relationship to their surroundings remains to be determined. It seems probable that they are due to variation in the country rock, and in the nature of the fissure, and I am at present engaged in the collection of data concerning them.

THE ORDER OF ARRIVAL OF THE MINERALS.

The detailed microscopic study of the veinstones has shown that the order of arrival of the minerals is not always the same. As a general rule the order, as shown by the relations of the constituent minerals, is:—

1. Quartz, mica, tourmaline, topaz, cassiterite, wolfram, stannine, and molybdenite.

2. Quartz, chlorite, fluor, chalcopyrite, mispickel, pyrite, and blende.

3. Lead and silver ores.

4. Secondary minerals such as other sulphides of copper, scheelite, carbonates, etc.

Wolfram is often earlier than cassiterite, and the latter is usually before tourmaline. Chalcopyrite is often before mispickel, and pyrite is usually later than both.

VEINSTONES OF UNUSUAL CHARACTERS.

In many instances the close relationship between igneous intrusion and lode formation is easily seen. The veins at Hemerdon,¹ Kit Hill, St. Michael's Mount, and Cligga Head are, as a rule, veins of greisen or pegmatite in the granite.² In other cases veinstones occur which have all the characters of pegmatites so far as texture and simultaneous crystallization are concerned. Such is the vein seen in the stope between the 148 and 160 levels, New Cook's Section, South Crofty, which shows large porphyritic crystals of wolfram, interlocked with coarsely crystalline quartz, mispickel, stannine, and chlorite, the minerals having crystallized at or about the same time. In Tin Croft Mine, again, there occurs a veinstone composed of quartz, altered felspar, chlorite, wolfram, and mispickel, with smaller proportions of cassiterite and fluorspar, in which the quartz wolfram and felspar penetrate one another.

Another occurrence of interest in this connexion is that of the pegmatite near the bottom of Dolcoath New Shaft, in which cassiterite occurred associated with garnet.

The association of cassiterite with acid intrusives is also shown by its frequent occurrence as a constituent of quartz-porphyry dykes ("elvans"). The occurrence at Parbola Mine is well-known, and microscopic examination has shown it to occur in many of the quartz-porphyry dykes of the Carn Menellis area.³

This constant connexion between the occurrence of the cassiterite with the products of the residual magma confirms the generally accepted idea that, by whatever means it was carried to and deposited in the lodes, the source of the metal was the granite magma.

¹ "On the Characters of some Cornish Veinstones": *Proc. Cornish Inst. of Engineers*, 1920.

² "On the Geology of St. Michael's Mount": *Proc. Roy. Geol. Soc. Corn.*, 1920.

³ "On the Mode of Occurrence of Cassiterite, etc.": *Proc. Roy. Geol. Soc., Corn.*, 1919.

EVIDENCE BEARING ON THE DEPOSITION OF CASSITERITE.

The structure of an alluvial pebble of cassiterite found in the Nanpusker Valley throws some light on the manner in which the mineral was deposited. The pebble consists of a roughly hemispherical nodule of cassiterite about half an inch in diameter with white quartz attached; through this quartz rays of cassiterite needles run radiately from the main mass. Microscopic examination shows that the cassiterite nodule is crystalline dark brown in colour and beautifully zoned. The rays consist of two kinds. Nearest to the nodule there are bunches of dark brown cassiterite needles, and further away there is a zone of yellow prisms of cassiterite with good crystal outlines, while outside these the quartz is crowded with small needles and skeleton crystals. The quartz is seen to be a mosaic of small irregularly shaped grains, which are in optical continuity around the ends of the cassiterite crystals and needles. The structure shows that the cassiterite either crystallized contemporaneously with the quartz or that crystallization took place in a silica jelly sufficiently viscous to hold the needles in position.

In conclusion, I must express my thanks to Mr. Harvey Kitto for collecting information with regard to Killifreth Mine, to Tehidy Minerals Company, Limited, for permission to inspect their plans and sections, and to the managers of the various mines visited for giving me valuable information and every facility for carrying out the work.

Platinum-bearing Rocks in the Lizard District.

By G. MCPHERSON, jun., Stud.I.M.M., and T. LAMB, Stud.I.M.M.

SOME remarks made at a meeting of the Cornish Institute of Engineers by Dr. R. H. Rastall directed attention to the possibility of platinum being found in the Lizard. In a paper upon "Ore Deposits of Igneous Origin", Dr. Rastall pointed out that in the Lizard the local characteristics were favourable to the presence of platinum, although no definite information of its occurrence had been reported. Much interest was aroused locally by these remarks, and the writers resolved to investigate the alluvials derived from the altered ultrabasic igneous rocks of the Lizard Group.

The main rock features of the Peninsula may be shortly indicated as follows. Against the Ordovician and Devonian schists of Cornwall lies the Lizard Group of greatly altered igneous and sedimentary rocks of the Basement Complex, separated from the schists by the Lizard fault and a much brecciated belt which traverses the Peninsula from east to west. The Lizard Group may be briefly described as consisting of mica- and hornblende-schists successively intruded by ultrabasic, basic, and acid bosses and dykes, all much altered by regional metamorphism. Minor intrusions are common, and frequently along the borders of the larger masses mixed rocks

are found, apparently derived by interaction between intrusive and country rock.

The ultrabasic bosses, which Dr. Rastall indicated as the possible sources of platinum, cover the centre and south-west of the Peninsula, and also appear as small intrusions in other parts. They consist of massive serpentine, and three main varieties have been previously outlined namely: Dunite-serpentine to the north, bastite-serpentine in the centre and south-east, and tremolite-serpentine to the west. The constant association of platinum with ultrabasic centres of dunite has been elsewhere noted, and it was considered that search around this mass of serpentine should prove most profitable. The dunite serpentine is a light-coloured rock, greyish-green, whitish or bluish in colour, very streaky, and containing octahedra and grains of magnetite and chromite. Its mass is on the highest central part of the Lizard plateau, and from the watershed streams arise which flow north to the Helford river, and east, south, or west to the sea. The alluvial bodies are very narrow and shallow, and contain little gravel, being mainly composed of clayey silt, and therefore not very favourable to the presence of mineral placers. No mineral deposits are known within this serpentine, which is exposed over an area of about $2\frac{1}{2}$ square miles.

The first tests were made by panning the surface of the alluvials with a small pan to recover any minerals of high specific gravity which might be present. The concentrates obtained were examined and found to consist of magnetite, a little chromite, and particles of dunite-serpentine, but no visible platinum. However, it was decided to assay the concentrates, and after fusion with litharge and fluxes, and cupellation of the resulting lead buttons, two minute beads of platinum were obtained weighing respectively 4 mg. and 35 mg. These were tested and definitely proved to be platinum. They indicate values of approximately 1.0 mg. Pt. per cubic ft. of silt. One of these beads was unfortunately mislaid, but the other remains in the custody of Mr. E. H. Davison, Lecturer in Geology at the School of Mines, Camborne.

As these values had been obtained from the surface silt of the alluvials, and as there was a strong probability of increased values being found near bedrock, it was decided to carry on further research. A prospecting licence was obtained and a pit sunk in one of the alluvials, near Tregadjack Farm, samples being taken at various depths and at bedrock. The results obtained were disappointing, from the economic point of view, as the alluvial proved to be fine silt down to bedrock, and there was practically no concentration of gravel or sand. A greater quantity of heavy concentrate per cubic foot was obtained near bedrock, but on this being examined it was found to be exactly similar to the previous ones, and contained no visible platinum. Samples from the stream beds were also obtained which, on panning, yielded similar concentrates.

The bedrock concentrate was handed over to Mr. E. H. Davison, who offered to assay it. He obtained a bead of platinum of .048 mg., thus indicating a value of approximately .024 mg. per cubic foot. This small value would suggest that the concentration of platinum is greater on surface than near bedrock, being due very probably to the fact that the dunite-serpentine has only been exposed by denudation for a short time, and thus no platinum placers have been formed. It was noted, while panning the silt, that several pebbles remained in the bottom of the pan with the heavy sands. These pebbles were always of one variety, a light green rock with a small proportion of metallic mineral finely interlaminated. It is believed by the writers that the fusion assay might reveal that the platinum is contained in this variety of dunite serpentine, but much further research is required to elucidate this point and others, such as whether the platinum exists in a minutely-divided free state or whether it is intimately associated with magnetite or chromite, as appears very probable from the very small amounts of platinum found in the assay.

There still remains a very small chance of an economic deposit being located, as there may be economic values of platinum in the laminated green serpentine, and judging by the amount of this rock found in the alluvials there must be a large body of it existing in the mass from which the streams flow.

Further research into these platinum-bearing rocks became impossible, owing to the writers leaving Cornwall, but there is still plenty of work waiting any enterprising geological student who cares to spend some leisure time in examining the Lizard alluvials and serpentines with a view to making clearer the facts of the above noted interesting occurrence of platinum.

REVIEWS.

THE GEOLOGY OF ANGLESEY. By EDWARD GREENLY. Memoirs of H.M. Geological Survey. Two volumes, 980 pages, 60 plates, 17 folding plates, 346 text-figures. 1920. Price 3 guineas. GEOLOGICAL MAP OF ANGLESEY, scale 1 in. to mile. Colour-printed. Price 2s. 6d.

THE appearance of this map and memoir is an event of first-rate importance in British geology, justly comparable with the publication of the North-West Highlands memoir, of world-wide renown. The two have, indeed, much in common; both result from the application of detailed large-scale mapping to regions prominently composed of ancient crystalline rocks, both formulate tectonic conceptions of great boldness and grandeur, and if the area of Anglesey be small, it may fairly be claimed to be more complex, less well-exposed, and to include a much greater variety of later formations. On the personal side, however, the present production stands apart from almost all its great predecessors in that it is substantially the work of one man, who single-handed and at his own expense has devoted more than twenty years of his life to its accomplishment.

The memoir is divided into five parts. Part I comprises an introduction, a history of previous research, and a very complete bibliography. Both in spirit and method the author's treatment of the work of his numerous predecessors leaves nothing to be desired, his admiration of their achievements is patent, and he concerns himself less with the restatement of dead controversies than with the recognition of each worker's contribution to our knowledge of the island. Part II, which occupies the remaining 352 pages of the first volume, is devoted to the study of the "Mona Complex", this being the term bestowed upon the series of ancient metamorphic rocks which occupy some two-thirds of the surface. Part III, occupying most of the second volume, deals with the later formations, which include representatives of nearly every Palæozoic system, an interesting set of Tertiary dykes, and widespread glacial deposits. Part IV is devoted to economics, and in Part V are gathered together a number of additional studies of the nature of postscripts, many representing important developments in the author's views on the Mona Complex during the progress of publication. Appendices give particulars and statistics of maps, specimens, and plates, while in a final supplement the author presents a connected account of his views on the metamorphism of the Mona Complex.

In Parts II and III the treatment is naturally stratigraphical, and has the advantage of a uniform plan. For each system a general account is first given. This commences, after a short introduction,

with a description of the petrology, followed by an account of the palæontology, after which the succession is established and a general view of the development of the formation throughout the island is given, and concludes with such matters as thickness, relations to other formations, and an attempt at a restoration of the physiography of the period. A separate chapter on the details of local development is provided for those who wish to study the formation in the field, and where necessary another chapter deals with the Tectonics. In the treatment of the Mona Complex the order is slightly varied, and many sections of the general account are replaced by whole chapters.

For the majority of geologists this account of the Mona Complex will be the outstanding feature of the work, and there can be no doubt that the decipherment of the succession and structure of this complicated and often highly crystalline tract is Mr. Greenly's crowning achievement. Work of such nature demands that petrological investigation go hand in hand with field work, and its successful issue must be ascribed to the author's capacity to carry out both lines of research. Out of a complex in which some seventy rock types are distinguished, including representatives of all the commoner types of sediments, spilites and associated jaspers, felsites, tuffs, and plutonic rocks ranging from serpentines to granites, he is able to establish the existence of a number of rock groups. These groups occur in several isolated regions, and in varying states of metamorphism, some even developing important changes of facies, but by the application of stratigraphical principles based on precise mapping, these difficulties have been overcome and a definite order of succession made out. Furthermore, the discovery of pebbles from one group in the conglomerates of another has given definite evidence of the chronological order in which this succession must be read. Thus we attain the conception of an original bedded succession of six principal subdivisions resting upon an ancient floor of yet older foliated rocks of which it is conjectured that certain gneisses form the only visible representatives. Into this bedded succession has been intruded a varied suite of plutonic intrusions, and the whole subjected to powerful regional metamorphism. Three special peculiarities of the Mona Complex are emphasized, its high sodium and titanium contents, which show themselves in the great predominance of albite among the feldspars and ilmenite among the iron ores, and its persistent green colour due to the abundance of anamorphic chlorite.

That this remote epoch was not without organic life is indicated by the discovery of annelid pipes and castings, while the jaspers are suspected to be altered radiolarian rocks.

The succession once established, the author proceeds to demonstrate his views on the tectonics of the Complex in a chapter of singular interest. The key to the interpretation is found in Holy Isle, where the effects of pitch and of two great normal faults combine

to bring in higher and higher tectonic horizons. Anomalies are at once apparent, which can only be reconciled by postulating very extensive inversions, and thus recumbent folding is established as the dominant structure of the Complex. Two great master-folds with complementary thrusts or slides are recognized from the evidence in Holy Isle, while upon other evidence, admittedly less complete, a third fold is also postulated. The impulse is throughout from the north-west, and amplitudes of the order of 60 miles are suggested. Superposed upon these primary structures are secondary and tertiary folds and thrusts of extreme complexity, with amplitudes which vary from thousands of feet to fractions of an inch, and to the stresses causing this later folding the author attributes the widespread regional anamorphism of the Complex. The apparently capricious variation in intensity of the metamorphism is shown to be dependent on the position of the beds in the tectonic succession, in accordance with the principle that anamorphism is a function of depth. To this, however, there is one striking exception, which has caused the author much concern before arriving at an explanation which he regards as satisfactory.

On the important question of the age of the Complex he is on firmer ground. He proves beyond the possibility of doubt that its regional metamorphism was complete, and that denudation had cut deeply into its most crystalline members before the basal Ordovician conglomerates were laid down. This in itself goes far to establish a pre-Cambrian age, but Mr. Greenly has gone further and obtained direct evidence from the mainland, where he has recognized pebbles from many horizons of the Complex in the basal Cambrian conglomerates and Harlech Grits. Thus, both the materials and metamorphism of the Mona Complex and—if the author's views upon tectonics be accepted—its recumbent folding are proved to be of pre-Cambrian age. The importance of this result to workers in other British areas of crystalline schists needs no demonstration.

With some understanding of the fascination which these ancient schists have exercised over the minds of so many great geologists, we turn almost reluctantly to the later formations. But the author's energies show no signs of flagging, and he devotes to their consideration 421 pages full of interesting facts and brilliant generalizations.

He commences with the study of a few small outliers of unmetamorphosed rocks intermediate in age between the Complex and the Ordovician. Of these certain volcanic rocks are correlated with the volcanic group of Bangor, while some sedimentary patches are regarded as the last relics of a former widespread sheet of Cambrian deposits, soon afterwards swept away by sub-Ordovician denudation.

Passing to the Ordovician, which after the Complex is the most widespread formation in the island, we learn that there seems to be

a complete succession, in which, notwithstanding the nearness of Snowdonia, no trace of volcanic activity is found. Save for the basal conglomerates and grits, the facies is graptolitic throughout, there being a complete passage from an Arenig and Llanvirn of typical Welsh character into a Glenkiln and Hartfell of striking similarity to the Scottish succession, which extends even to a development of the "Barren Mudstone" facies. There is no sign of overlap in the formation until the northern coast is reached, when all the zones below the Glenkiln suddenly disappear, and we are confronted with a distinct northern facies; this phenomenon, so long a source of misconception, becomes in the author's hands the key to the interpretation of the post-Silurian earth movements.

Silurian rocks, once probably widespread, are now preserved only in the deep infold of Parys Mountain, which has yielded a rich Valentian graptolite fauna, and is also the seat of remarkable metasomatism. These phenomena, of which the once famous copper ores represent a certain phase, are fully treated in a separate chapter.

Attention is next directed to the great suite of Palæozoic intrusions, whose dykes are so conspicuous upon the map. They are shown to have a wide range in composition, from the well-known "Hornblende-picrites" to felsites, and cogent reasoning establishes their genetic connexion with the post-Silurian earth movements.

As would be expected from its geographical position, these manifestations of the Caledonian crustal disturbances have powerfully affected Anglesey, and their effects are discussed in another absorbing chapter. For the second time we meet with signs of an overwhelming impulse from the north, which becomes increasingly evident as we pass away from the mainland. Folding becomes isoclinal, cleavage develops, minor thrusts appear, and finally we encounter a gigantic rupture curving from coast to coast, along which the whole northern region of Anglesey with its distinct northern facies, both of Mona Complex and of Ordovician, has been driven southwards for a score of miles. This great dislocation has been named the "Carmel Head Thrust Plane", and the shearing, mylonization, and other dynamical phenomena seen along its course strongly recall the lesser thrust planes of the North-West Highlands. The sudden appearance of the northern Ordovician facies now becomes intelligible, and we see that its apparent interstratification with the schists of the Complex is due to the rupturing of infolds, produced during the same great disturbances. In an interesting comparison of these movements with those of the Mona Complex, upon which they have been superimposed, the author shows that the phenomena are throughout those of a higher tectonic zone; recumbent folding gives place to fracture, widespread inversion is absent, and foliation and anamorphism are replaced by mineral changes of a katamorphic nature.

Of the Upper Palæozoic formations the Lower Old Red Sand-

stone has a small development of typical character, and does not appear ever to have had a wide distribution in the island; after its accumulation occurred a final feeble renewal of the southward folding impulse.

With the Carboniferous we encounter once more a widespread formation. Its most prominent member is the Carboniferous Limestone, which presents all the normal characters save for an unusual development of transgressive pebbly sandstones at several horizons. All three subdivisions of the *Dibunophyllum* zone can be recognized, and some cherts at the top of the series are referred to the *Posidonomya* zone, but nothing older can be definitely proved, and it is shown that the whole series disappears by gradual overlap in a south-westerly direction. A thin "Millstone Grit", with a peculiar kaolinite matrix, succeeds the limestone, and passes up into Coal Measures, which are only known from mining records, being entirely buried beneath the drifts and alluvium of the Malldraeth Marsh. Fourteen coal seams are known, mostly of small value. These indubitable representatives of the Carboniferous are succeeded unconformably by a series of red sandstones and marls, which have been referred to various geological horizons. The author produces evidence for their reference to the Upper Coal Measures, and correlates them with the well-known Red Measures of the Midland coalfields. Following the deposition of these beds, earth movements again took place, but the horizontal component so conspicuous in the older stresses is now absent, and all the faults are of the "normal" type, one of them being of great magnitude.

The Mesozoic era being unrepresented in Anglesey, though there is reason to believe that several of its formations were once deposited there, the next rocks described are the interesting Tertiary dykes, of which no fewer than thirty have been mapped.

The glaciation, which next claims attention, has left traces everywhere in the form of drifts or ice-worn features. Numerous striæ and trains of erratics show that the island was traversed by ice moving in a south-westerly direction, and the author's evidence confirms the commonly accepted view that this ice formed part of a great ice sheet, which entirely filled the Irish Sea Basin. Even the highest hills of Anglesey were deeply buried and certain overflow notches show that the ice sheet pressed up against the Carnarvonshire mountains to the height of at least 1,700 feet. Two distinct boulder clays can be distinguished on the eastern coast, separated in places by fluvio-glacial gravels which are taken to indicate an important recession of the ice, though the author refuses to commit himself to a more precise opinion as to its magnitude. Great numbers of extra-insular boulders occur in the drifts, and afford an opportunity for some interesting speculations on the submarine geology of the south-eastern part of the Irish Sea.

A final chapter on the development of the present land surface, which includes the consideration of the Pliocene platforms of erosion,

and the author's already published theory of the origin of the Menai Strait brings the stratigraphical portion of the memoir to a close. The contents of the remainder of the second volume have already been outlined.

In the course of this review no mention has yet been made of the assistance received by the author from other workers. All the fossil identifications are the work of specialists, of whom Miss Elles also contributes an essay on the graptolite sub-faunas, and in the field much help has been rendered by the fossil collectors of H.M. Geological Survey; Mr. J. O. Hughes has carried out a large number of rock analyses, and several distinguished petrologists have lent their aid on special points. All this and much other assistance is duly recognized by the author, who is throughout meticulous in his acknowledgment of help received.

The memoir is well illustrated, most of the 346 clear text-figures are from Mr. Greenly's own pen, while of the 60 plates the greater number are reproductions of photographs taken for H.M. Geological Survey, and of the usual excellent quality; a few are less satisfactory and a number of the collotype plates of rock-sections are disappointing. There are also seventeen folding plates, mainly horizontal sections, but including also some coloured reproductions of the original field maps, a welcome innovation which will be of great value to the field geologist and serves to demonstrate the detailed precision of the author's mapping.

Accompanying the memoir is a colour-printed geological map of Anglesey upon the one-inch scale, which possesses certain advantages. Portions of several sheets of the ordinary issue have been combined to form a single sheet covering the whole island and a number of additional place-names mentioned in the text have been inserted. The reduction of the geological boundaries from the six-inch to the one-inch scale seems to have been well done, and the common error of inserting too much detail has been wisely avoided. The colour model, too, has been skilfully prepared and shows the various formations to advantage. But the general appearance of the map, and what is more, its utility to the geologist, suffers greatly from the bad reproduction of the outline. There seems to be an impression at Southampton that in a map of this kind only the colours matter and that the printing of the topographical detail is of secondary importance. Every field geologist knows the contrary. In the present map the colour printing is adequately done, though the tint given to the Ordovician on the map hardly corresponds with that shown on the legend. But the outline plate is bad, the printing of the title "Anglesey" shows this glaringly, all the lines are thick and lacking in sharpness, the contours are invisible, the smaller place-names all but unreadable, while the muddy grey tint which has been used in the printing to conceal these defects hinders the discernment of the topography under its coating of colour and makes it difficult to follow the author's descriptions.

But these defects are no part of Mr. Greenly's work, and it remains to congratulate him upon an absorbing account of a very remarkable achievement. We understand that he has lost no time in transferring his attention to the Carnarvonshire mainland, and we await with eager interest the results of his work in that equally classic area.

T. C. N.

THE APPENDAGES, ANATOMY, AND RELATIONSHIPS OF TRILOBITES.
By PERCY E. RAYMOND. Memoirs of the Connecticut Academy of Arts and Sciences. Vol. VII. 1920. 169 pp., 11 plates and portrait, text-figs.

THE researches of the late Professor C. E. Beecher on the structure of Trilobites are familiar to all palæontologists, and his restorations have been widely copied in textbooks. It is perhaps not generally known that his writings on the subject were all preliminary to an extensive monograph on which he was engaged up to the very day of his death in 1904. The materials for this monograph, as he left them, comprised a large number of specimens carefully developed, and photographs and drawings of these, but no written notes. At the invitation of Professor Schuchert, who succeeded him in the chair of palæontology at Yale, one of Beecher's pupils, Professor Percy E. Raymond, of Harvard, has taken up the unfinished task, and in this volume, dedicated to the memory of his master, gives the results of his study of the material, illustrated largely by fine reproductions of Beecher's own photographs and drawings.

In a foreword by Professor Schuchert some interesting details are given of Beecher's methods of work. The pyritized specimens of *Triarthrus*, from the Utica shale of Rome, New York, which provided the main subjects of investigation, are as a rule less than an inch long, and the cleaning of the minute details of their appendages was a difficult and tedious business. After various chemical methods had been tried without success, it was found best to depend on abrasives (carborundum, emery, and pumice) applied with pieces of rubber. As development went on, the rubbers were reduced in size so as to abrade only minute areas. The beautiful photographs reproduced in this volume were taken by immersing the specimens in liquid Canada balsam and photographing through a cover-glass with a vertical camera.

Although the primary object of this memoir is to give detailed descriptions and figures of Beecher's material, the author has also re-examined most of the known specimens of Trilobites exhibiting the appendages. In particular he has studied the material worked out by Dr. Walcott, whose help in the communication of specimens and photographs is acknowledged, and he discusses at length the various problems connected with the morphology, phylogeny, and bionomics of the group. The monograph, therefore, covers much the same ground as that of Dr. Walcott, reviewed in this Magazine

two years ago (GEOL. MAG., 1919, pp. 359-63), and a comparison of the conclusions reached by the two writers is of particular interest. Their substantial agreement on all the main points of structure is of importance as showing that our knowledge of the Trilobites' appendages rests upon a sure basis. It is only on matters of detail that there is difference of opinion.

The author has been unable to convince himself of the presence of the epipodites and exites described in *Neolenus* and some other genera by Walcott, and he considers that the appendages were in all cases simply biramous. The two branches are connected with a single basal segment produced inwards to form a gnathobase, or, as Raymond prefers to call it, "endobase." Walcott described this basal segment as formed by the fusion of two segments, the coxopodite and basipodite. Raymond regards it as representing the coxopodite alone, the second free segment being the basipodite, and he states that the exopodite articulates with both of these segments. At the point of attachment of each coxopodite with the body is a calcareous process extending "down from the dorsal test just inside the line of the dorsal furrow". These processes are designated "appendifers", and are compared with the entopophyses of *Lamulus*.

In his recent monograph Walcott adheres to his interpretation of the sections of *Calymene*, *Ceraurus*, and *Acidaspis* as showing that these genera possessed spirally coiled branchiæ. Raymond discusses at length the evidence for the existence of these remarkable structures, and while admitting the difficulty of interpreting the appearances seen in the sections, he comes to the conclusion that the appendages in these genera did not differ in essential structure from those of other Trilobites in which the limbs are exposed on the surface of the fossils.

On the question of the affinities of the Trilobita, Raymond is in agreement with Walcott in regarding them as most nearly related to the Crustacea. He even includes them within the sub-class, and regards the other groups of Crustacea as derived directly from Trilobites. In taking this view he has, perhaps, hardly allowed due weight to the non-crustacean characters alluded to in the review already quoted (GEOL. MAG., 1919, p. 363). He also considers it possible that all the other groups of Arthropoda may yet be traced back to a Trilobite ancestry, but he is careful to point out the wide gaps that remain to be filled in before this can be done.

Many criticisms might be offered on points of detail. For example, he states that "the exact homology, segment for segment, between the walking legs of the trilobite and those of many of the Malacostraca, even the Decapoda, is a striking instance of retention of primitive characteristics in a specialized group". This exact homology, however, is only obtained by assuming that the exopodite articulates with both the coxopodite and the basipodite, an arrangement not found in any Malacostracan, nor, indeed, in any Crustacean.

If it were verified, this character would be much more important than a mere coincidence in the number of segments.

On one point the student of recent Crustacea will certainly dissent from Professor Raymond's conclusion. As he states, "Since the earliest times there has been a constant temptation to compare the depressed shields of the trilobites with the similar ones of Isopods," and he has succumbed to this temptation so far as to suppose that the Isopods may have been derived directly from Trilobites and independently of the other Malacostraca. It can be stated with some confidence that this view receives no support from what we know of the structure of recent Isopods. If it is ever permissible to draw phylogenetic conclusions from the facts of comparative anatomy, then it is as certain as anything of the sort can well be that the Isopoda have been evolved from a primitive Mysidacean type. The intermediate steps of this descent are indicated not obscurely, although overlain by divergent specializations, in the Cumacea and Tanaidacea. The resemblances in general aspect between certain Trilobites and certain Isopods are very remarkable indeed, but the view that they indicate descent of the one group from the other can only be compared with those fantastic speculations which would derive whales from Ichthyosaurs and bats from Pterodactyls.

Professor Raymond's discussions of the course of evolution within the group of Trilobites, and of their probable habits and mode of life, are especially interesting and suggestive. The whole memoir, however, deserves careful study by all students of fossil and recent Arthropoda. An index would have helped in its use, but this want is to some extent supplied by a full and methodically arranged table of contents. A word of praise is due to the excellent portrait of Professor Beecher which forms the frontispiece.

W. T. CALMAN.

SPECIAL REPORTS ON THE MINERAL RESOURCES OF GREAT BRITAIN.
Memoirs of the Geological Survey.

VOL. XIX: LEAD AND ZINC ORES IN THE CARBONIFEROUS ROCKS OF NORTH WALES. By BERNARD SMITH, M.A. pp. iv + 162, with 3 plates and 25 figures. 1921. Price 5s. 6d. net.

VOL. XXI: LEAD, SILVER-LEAD, AND ZINC ORES OF CORNWALL, DEVON, AND SOMERSET. By HENRY DEWEY. pp. iv + 72, with 4 plates and 14 figures. 1921. Price 2s. 6d. net.

VOL. XXII: THE LEAD AND ZINC ORES OF THE LAKE DISTRICT. By T. EASTWOOD. pp. iv + 56, with 1 plate and 4 figures. 1921. Price 2s. net.

ONE of the most difficult and interesting problems still confronting the scientific student of metallogeny is the elucidation of the origin of the ores of lead and zinc that are found in such large quantities in limestone strata of various ages. At one time it was generally believed that the vein-fillings had been deposited from meteoric waters percolating downwards, or by some form of "lateral

secretion". However, it was soon recognized that these theories left the source of the metals unexplained, and the frequent presence of fluorspar in large quantities was also a difficulty. In America many geologists appear still to hold that meteoric waters are the chief agent in the formation of lead-zinc deposits, especially those of the Mississippi valley, but in Europe the tendency is to seek a deep-seated origin, and to refer the genesis of both ores and gangue to the intrusion of igneous magmas. In the case of the lead-zinc veins of Cornwall, lying in slaty rocks and in obvious relation to granite intrusions, this connexion may be regarded as demonstrated. With the ores in the Carboniferous limestone of North Wales and northern England, it is still a matter of speculation.

The metalliferous veins of the Lake District belong to a type in many respects intermediate between the other two. They lie in Ordovician rocks, and their relations to the intrusions are obscure. Many of them carry a fair amount of copper, and the principal gangue mineral is quartz, with subordinate barytes; calcite and dolomite are rather uncommon, while fluorspar is exceedingly rare.

A careful consideration of the facts set forth in these three memoirs should go far towards solving the problem, and we look forward with much interest to the publication of the remaining volumes dealing with ores of lead and zinc. The evidence thus brought together will also be of great value in settling another doubtful point, namely, the age, or perhaps of more importance, the date of the latest phases, of the mineralization, which in some instances appears to have continued into post-Triassic times, as shown, among other cases, by the ores in the Dolomitic Conglomerate in the Mendips and the sandstone cemented by galena at Alderley Edge.

These publications follow exactly the plan of the other volumes of the series: they contain an admirably full and detailed account of all the mines that have been worked in their respective areas, derived partly from personal inspection by the authors, and when such was impossible, from a study of old mine plans and all other available sources of information. Theoretical questions are also briefly discussed, and it is interesting to note that Mr. Bernard Smith obviously inclines towards a magmatic origin for the ores of North Wales. The general impression gained from a perusal of these memoirs is that in spite of present economic conditions there may yet be a future for lead and zinc mining in North Wales, if an extended policy of drainage tunnels can be carried out: much has already been done in this way, and it is devoutly to be hoped that means may be found to carry on and extend this work. In Cornwall, also, it appears probable that the deposits of lead and zinc are by no means exhausted: many of the veins are also extremely rich in silver and may eventually again prove of considerable value. Many of the Lake District veins are not yet fully explored, and there are possibilities for barytes production in the future.

R. H. R.

DESCRIPTION OF ARTHUR'S SEAT VOLCANO. By B. N. PEACH, LL.D., F.R.S. Second Edition. Mem. Geol. Survey of Scotland. pp. 26, with a coloured map and 4 figures. 1921. Price 2s. 6d. net.

THE first edition of this admirable little memoir was published in 1911. It was a reprint, with slight changes, of the description of the area in the second edition of *The Geology of the Neighbourhood of Edinburgh*. In this second edition Dr. Flett has made a few unimportant alterations in the text, and has added another valuable feature in an appendix describing the characters and classification of the volcanic rocks, according to the modern nomenclature of the Scottish Carboniferous petrographical province.

THE ECONOMIC ASPECTS OF GEOLOGY. By C. K. LEITH. pp. xiii + 457. New York: Henry Holt & Co. 1921.

ONE of the most noteworthy developments of recent years in scientific thought is the general recognition of the fact that all science has an actual or potential economic value. The old lines of demarcation between "pure" and "applied" science are being rapidly swept away, and in no field is this more true than in geology. There is, in point of fact, no such thing as economic geology. What is ordinarily meant by this term is the special application of geological law and theory to problems of present practical moment. During the last seven years this has become abundantly manifest, and an enormous amount of additional interest has been imparted to our science by the realization of its importance as a factor in world-politics and world-industry. There is scarcely a single field of human endeavour in which geology has not some part; mineral resources are, in fact, the foundation of a great part of trade and industry, and their political influence cannot be over-estimated. Another fact now generally recognized is the economic value of purely theoretical investigations. It is unnecessary to labour this point; it must suffice to say that though it is impossible to foresee exactly when a theoretical investigation will become of technical value, it always does so sooner or later. As an example of this we will only mention the bearing of theories of magmatic differentiation on the origin of ore-deposits and their discovery and exploitation on a commercial scale.

Such are the ideas that Professor Leith has set himself to develop in this book and well has he performed his task. It is shown that all branches of geology, even the most apparently abstract, have served or may serve some useful purpose. The first 300 pages are occupied by a systematic account of the occurrence and distribution of mineral deposits, each discussed under two headings, geological and economic. The geological sections are necessarily brief and somewhat sketchy; the economic sections describe the distribution, output, and applications of the minerals and the principal facts

relating to markets, financial and political control and possibilities of future developments.

The latter third of the book is occupied by chapters on exploration and development, conservation of mineral resources, valuation and taxation, the legal and international aspects of mineral resources, geology in war and in relation to engineering, and the training of the economic geologist. All these chapters contain admirable summaries of their subjects, and should be widely read. Perhaps of most interest are those on the national and international aspects of mineral resources. These are, of course, mainly written from the American standpoint, and it is striking to find that the United States, the oldest and greatest democracy, shows the least tendency of any country towards State ownership of minerals. Professor Leith gives some wise words of warning as to the dangers of subjecting industries of such paramount importance to the cumbrous, slow-moving, and unenterprising control of a bureaucracy.

There is much wisdom, also, in his advice as to the training of the economic geologist; he insists as strongly as possible on the necessity for a wide general education and a good grounding in pure science. In fact, his view amounts to this: "Learn the pure science and the economic side will look after itself." That is to say, the applications will be acquired gradually as a result of experience and practice. No man can tell beforehand in what particular subject he will specialize, and it is impossible to study them all in detail in an educational course. Nevertheless, much may be done by devoting special attention to the illustration of theory by examples of technical application, and teachers, by dealing fully with the theory underlying cases that are understood, may pave the way to the elucidation of others, of equal importance, that are still involved in mystery.

R. H. R.

PRODUCTS OF THE EMPIRE. By S. C. CUNNINGHAM, B.A. pp. 299. Oxford, 1921.

THIS little book aims apparently, and not unsuccessfully, at giving a short popular account of the assets of the British Empire in so far as these relate in the first place to food, drink, drugs, and tobacco, and in the second to raw materials and the produce of mines. As the author points out, there never has been a complete survey of all the Empire's resources, but the Royal Commission appointed in 1912 has issued reports on the produce of certain countries, and these have yielded much information of value. The chapters in this book which will be of most interest to the geologist are, naturally, those upon the metals, coal, and petroleum. The metallic produce is summarized in a useful table at the end of the second chapter on this part of the subject, and the sources of supply, both foreign and British, are duly set out; under the latter

head are included also known deposits which are at present entirely or comparatively unworked, as well as those from which the metals are at present obtained. Thus we read that for aluminium the foreign sources of supply are France, Italy, and the United States, the present British source is Ireland, and the British sources of the future are British Guiana, India, and Australia. The various chapters of the book give an interesting assortment of varied information. Thus, in that on coal we find accounts of the derivation of the word, the origin of coal in geological history, the discovery of coal by man, the beginnings of coal mining, the difficulties and dangers of the process, the kinds of coal, the probable duration of the supply, and the reserves of coal in the Empire.

F. H. A. M.

A CATALOGUE OF BRITISH SCIENTIFIC AND TECHNICAL BOOKS.
pp. xviii + 376. British Science Guild, 6 John Street, Adelphi,
London, W.C. 2. Price 10s. net.

THIS handsome volume, prepared by a Committee of the British Science Guild, is a bibliography of standard works on all departments of science, using the term in its broadest sense. It cannot fail to be of the greatest value to all scientific workers, and is remarkably cheap at the price, as books go now. Mineralogy, geology, and palæontology are treated as separate subjects, and each is subdivided under different headings. The distinction between economic geology and economic mineralogy has evidently proved difficult to carry out in practice, as might have been anticipated, and these two sections would have been better combined into one. Also we should like to see added in a future edition a few more such books as Lindgren's *Mineral Deposits* and Emmons' *Economic Geology*. The literature of oil geology is also very incomplete. On the other hand, the selection of books on what may be called the pure science side is very good, and many standard but out-of-date works are wisely omitted. In this category, however, we do not include Lyell's *Elements*, which we have been unable to find under any heading: this book can never grow old, and should be read by all students.

In this catalogue are given the number of pages, date, name of publisher, and price of each book.

GEOLOGICAL ITINERARIES IN ANGLESEY. By EDWARD GREENLY,
D.Sc. pp. 12. Liverpool, 1921.

THESE itineraries were originally drawn up by Dr. Greenly at the request of Mr. T. A. Jones, secretary of the Liverpool Geological Society, to serve as a guide for leaders of excursions and other geologists visiting Anglesey. They contain precise directions as to how to reach the different localities, with a summary of what

is to be seen there, and have proved so useful that Mr. Jones has had them printed at his own expense as a small pamphlet. Copies can be obtained at 7d. each post free, or 6s. a dozen from T. A. Jones, Esq., 27 Rockfield Road, Anfield, Liverpool. We hope enough copies will be sold to cover at least the greater portion of the cost involved in printing, which in these days is no light matter.

REPORTS AND PROCEEDINGS.

EDINBURGH GEOLOGICAL SOCIETY.

March 16th, 1921.—Mr. E. B. Bailey, M.C., B.A., F.G.S., F.R.S.E.
in the chair.

“Glacial Drainage Phenomena in the Neighbourhood of Edinburgh.” By D. Anderson, M.A.

Mr. Anderson gave a minute description of the lie of the land to the east, south, and west of Edinburgh, particularly in connexion with a number of natural features generally supposed to be glacial channels, which conveyed away the melt waters of the great Ice Sheet at the time of its retreat owing to warmer conditions of climate coming on. The address was illustrated by lantern views and a map. Certain of the glacial channels, as those at Fairmilehead, Hunters Tryst, the White Hill, or “T” Plantation, Blackford Hill, Braid Burn, and a fine example of Kingsknowe on the golf course, were specially noticed and illustrated. A main point of the address was to connect the system of glacial drainage channels of East Lothian, described by Messrs. Bailey and Kendall, with those in the neighbourhood of Edinburgh.

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- HUME (W. F.). *The Rift Valleys and Geology of Eastern Sinai.* 8vo. Cloth. 1901. 2s.
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- LEITH (C. K.) AND MEAD (W. J.). *Metamorphic Geology. A Textbook.* 8vo. Illustrated. Cloth. New York, 1915. £1.
- POSTLETHWAITE (J.). *Mines and Mining in the (English) Lake District. Third edition.* 8vo. Illustrated. Cloth. Whitehaven, 1913. 5s.
- REED (F. R. C.). *The Geology of the British Empire.* pp. 480. 8vo. With 12 folding maps and 13 maps and sections in the text. Cloth. London, 1921. £2.
- RUTLEY (F.). *Elements of Mineralogy.* 20th ed. Revised with an introduction by G. T. Holloway. pp. xxii+394. Cr. 8vo. Illustrated. Cloth. 6s.
- TEALL (J. J. HARRIS), M.A., F.G.S. *British Petrography: with special reference to the Igneous Rocks. With 47 plates.* Royal 8vo. Cloth. £3 3s. net.
- VAN DEN BROECK (E.), MARTEL (E. A.), AND RAHIR (EDM.). *Les Cavernes et les Rivières souterraines de la Belgique.* Bruxelles, 1910. 2 vols. 8vo. With 26 plates and text illustrations. £1 10s.

JUST PUBLISHED.

Catalogue of the Fossil Bryozoa (Polyzoa) in the Department of Geology, British Museum (Natural History). *The Cretaceous Bryozoa* (Polyzoa). Volume III. The Cribrimorphs, Part I, by W. D. LANG, Sc.D. pp. 269, 8 plates, and 115 text-figures. With general index, index to systematic names of Polyzoa and explanation of Plates. 8vo. Cloth. £1 10s.

The Jurassic Bryozoa, by J. W. GREGORY, D.Sc. pp. [viii] 239, 22 woodcuts, and 11 plates. 8vo. Cloth. 1896. 10s.

The Cretaceous Bryozoa, by J. W. GREGORY, D.Sc. Vol. i, pp. xiv, 457, 64 woodcuts, and 17 plates. 8vo. Cloth. 1899. 16s.

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A. SMITH WOODWARD, LL.D., F.R.S.

DECEMBER, 1921.

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THE GEOLOGICAL MAGAZINE

VOLUME LVIII.

No. XII.—DECEMBER, 1921.

ORIGINAL ARTICLES.

Fossils from Western Persia.

By ETHEL D. CURRIE, B.Sc., Hunterian Museum, Glasgow University.

(PLATE XI.)

A COLLECTION of fossils from the area of Pusht-i-Kuh, on the western border of Persia, has been forwarded recently to Glasgow University by Dr. W. R. Smellie.

The geology of Luristan in Persia has been studied by J. de Morgan (Miss. Sci. Perse, vol. iii, pt. i, *Etude Géol.*, 1905), whose collection of fossils has been described by Cotteau, Gauthier, and Douvillé (ibid., pts. ii, iii, and iv). With one or two exceptions the fauna collected by Dr. Smellie is similar to that of de Morgan.

Dr. Smellie made his collection from Upper Cretaceous beds and their age is apparently Senonian. The collection consists chiefly of echinoids, but includes also various molluscs, brachiopods, and bryozoa.

The following echinoids are present :—

1. *Cidaris persica* Cotteau & Gauthier, 1895 (ibid., pt. ii, p. 79, pl. xiii, figs. 1-5).

Localities.—Aftâb, Dere-i-Sahir, Endjir-kuh (coll. de Morgan). Shakarau, Warriz, Kabir Kuh 2 (coll. Dr. Smellie).

One specimen is greatly distorted and another is merely a segment of a test. The segment resembles *C. persica* in all respects except that the number of granules in the ambulacral areas increases to eight near the ambitus instead of six as in other specimens.

	DIAM.	HEIGHT.
<i>Dimensions.</i>	14 mm.	9·5 mm.

2. *Rhabdocidaris morgani* Gauthier, 1902 (ibid., pt. iii, p. 145, pl. xx, figs. 3-6).

The exact locality at which de Morgan originally obtained the species has been lost. Dr. Smellie's specimens are a fragment of a test and an interambulacral plate. These are from Warriz.

3. *Salenia cossira* Cotteau & Gauthier, 1895 (ibid., pt. ii, p. 83, pl. xiii, figs. 13-19).

Localities.—Dere-i-Sahir, Endjir-kuh, Aftâb (de Morgan). Warriz, Atash Gah (Dr. Smellie).

	DIAM.	HEIGHT.
	mm.	mm.
<i>Dimensions.</i>	17	11
	17·5	11
	18·5	12·5
	20	14·5
	23·5	16·5

4. *Goniopygus superbis* Cotteau & Gauthier, 1895 (ibid., p. 101, pl. xvi, figs. 5–10).

Localities.—Dere-i-Sahir, Awasa, Aftâb (de Morgan). Warriz, Anjir (Dr. Smellie).

	DIAM.	HEIGHT.
	mm.	mm.
<i>Dimensions.</i>	24 mm.	14 mm.

5. *Orthopsis morgani* Cotteau & Gauthier, 1895 (ibid., p. 87, pl. xiv, figs. 6–9).

Localities.—Dere-i-Sahir (de Morgan). Shakarau, Warriz, Kabir Kuh 2, Anjir, Kurac Kalul (Dr. Smellie).

	DIAM.	HEIGHT.
	mm.	mm.
<i>Dimensions.</i>	16	10
	26	12
	28	12·5

6. *Orthopsis globosa* Cotteau & Gauthier, 1895 (ibid., p. 89, pl. xiv, fig. 10–14).

Localities.—Aftâb, Dere-i-Sahir (de Morgan). Warriz, Dahnah, Pire Mahommed, Anjir (Dr. Smellie).

	DIAM.	HEIGHT.
	mm.	mm.
<i>Dimensions.</i>	29	17
	29·5	17

The specimens are all more or less distorted. *O. globosa* is distinguished from *O. morgani* by its globular form, its elongated and oblique pores, and the different arrangement of the tubercles.

7. *Actinophyma spectabile* Cotteau & Gauthier, 1895 (ibid., pt. iii, p. 151, pl. xx, figs. 7–10).

Localities.—Endjir-kuh, Aftâb, Tagh-i-Mowla, Meima, Tang-i-Hiana (de Morgan). Warriz, Kabir Kuh 2, Tang-i-Nyaz (Dr. Smellie).

The specimens are rather broken and distorted but show the sutural impressions and fossettes which distinguish this genus from Cyphosoma.

8. *Coptodiscus noemiae* Cotteau & Gauthier, 1895 (ibid., pt. ii, p. 77, pl. xii, figs. 8–14).

Localities.—Endjir-kuh, Aftâb, Kuh-Mapeul, Dere-i-Sahir, Awasa (de Morgan). Warriz, Atash Gah, Dahnah, Anjir (Dr. Smellie).

	DIAM.	HEIGHT.
	mm.	mm.
<i>Dimensions.</i>	13	6·5
	13·5	6·5
	17	7
	25·5	7·5
	27·5	10

9. *Holctypus circularis* Cotteau & Gauthier, 1895 (ibid., p. 75, pl. xii, figs. 5-7).

Localities.—Dere-i-Sahir (de Morgan). Dahnah, Anjir (Dr. Smellie).

	DIAM.	HEIGHT.
	27 mm.	13 mm.

10. *Holctypus inflatus* Cotteau & Gauthier, 1895 (ibid., p. 73, pl. xii, figs. 1-4).

Localities.—Aftâb (de Morgan). Shakarav, Warriz, Dahnah (Dr. Smellie).

	DIAM.	HEIGHT.
	mm.	mm.
<i>Dimensions.</i>	47·5	29·5
	26	13
	15·5	9·5

H. inflatus resembles *H. circularis* in many respects, but differs therefrom by being much more timid.

11. *Echinoconus douvillei* Cotteau & Gauthier, 1895 (ibid., p. 70, pl. xi, figs. 9-13).

Localities.—Dere-i-Sahir, Aftâb (de Morgan). Warriz, Kabir Kuh 1 and 2, Dahnah, Anjir, Pire Mahommed, Atash Gah, Tang-i-Nyaz, Kurac Kalul (Dr. Smellie).

	LENGTH.	BREADTH.	HEIGHT.
	mm.	mm.	mm.
<i>Dimensions.</i>	16	14	12·5
	26·5	24	18
	33·5	30	25·5
	43·5	38·5	35·5

The collection also includes two very large individuals not found in situ but on tombs, near the outcrop of Cretaceous beds at Tang Qayah. In one of these the upper half is missing, but the base is perfectly preserved and measures 97 mm. in length. The other specimen, which is not well preserved, has the dimensions:—

LENGTH.	BREADTH.	HEIGHT.
76·5 mm.	72 mm.	61 mm.

12. *Pyrina orientalis* Cotteau & Gauthier, 1895 (ibid., p. 68, pl. xi, figs. 1-8).

Localities.—Dere-i-Sahir, Endjir-kuh (de Morgan). Shakarav, Warriz, Kabir Kuh 1, 2, and 3, Qayah, Anjir, Pire Mahommed, Kurac Kalul (Dr. Smellie).

	LENGTH.	BREADTH.	HEIGHT.
	mm.	mm.	mm.
<i>Dimensions.</i>	18	16	13
	26	22	17·5
	28·5	23·5	18·5
	32	28	22

13. *Pygurostoma morgani* Cotteau & Gauthier, 1895 (ibid., p. 52, pl. viii, figs. 1-5).

Localities.—Aftâb (de Morgan). Worazan, Dahnah, Kurac Kalul (Dr. Smellie).

Specimens poorly preserved and flattened.

	LENGTH.	BREADTH.	HEIGHT.
	mm.	mm.	mm.
<i>Dimensions.</i>	57·5	46	21·5
	62	51	23·5

14. *Parapygus petalodes* Cotteau & Gauthier, 1895 (ibid., p. 58, pl. ix, figs. 4-5).

Localities.—Aftâb (de Morgan). Dahnah, Anjir (Dr. Smellie).

	LENGTH.	BREADTH.	HEIGHT.
<i>Dimensions.</i>	42 mm.	33·5 mm.	21·5 mm.

15. *Catopygus morgani* Cotteau & Gauthier, 1895 (ibid., p. 60, pl. ix, figs. 6-9).

Localities.—Dere-i-Sahir (de Morgan). Kabir Kuh 1 (Dr. Smellie).

	LENGTH.	BREADTH.	HEIGHT.
<i>Dimensions.</i>	32·5 mm.	28 mm.	23·5 mm.

16. *Pseudocatopygus declivis* Cotteau & Gauthier, 1895 (ibid., p. 63, pl. ix, figs. 13-17).

Localities.—Aftâb (de Morgan). Kurac Kalul (Dr. Smellie). One specimen (flattened).

17. *Vologesia tataosi* Cotteau & Gauthier, 1895 (ibid., p. 66, pl. x, figs. 5-8).

Localities.—Aftâb (de Morgan). Dr. Smellie's one specimen is from Kabir Kuh 1. The posterior of the test is broken, but its length must have been about 55 or 56 mm., breadth 46·5 mm., height 34 mm.

18. *Holaster morgani* Cotteau & Gauthier, 1895 (ibid., p. 19, pl. iii, figs. 1-4).

Localities.—Dere-i-Sahir (de Morgan). Warriz, Tang-i-Nyaz (Dr. Smellie).

Specimens poorly preserved and distorted.

19. *Hemipneustes persicus* Cotteau & Gauthier, 1895 (ibid., p. 15, pl. ii, figs. 1-6).

Localities.—Aftâb, Dere-i-Sahir (de Morgan). Worazan, Warriz, Anjir (Dr. Smellie).

20. *Epiaster Smellii* n. sp.

Diagnosis.—Shape of test varies greatly. It may be tumid to flat, and the length may be equal to, or greater than, the breadth. Figs. 1-4 represent four typical specimens.

Peristome is very near the anterior border. It is almost round, and has a small crenulated lip.

Periproct.—The posterior border is truncated obliquely downwards and inwards forming a distinct area outlined by a ring of nodules. The periproct is circular and is situated in the upper portion of this area.

Apical disc.—Almost central; slightly posterior.

Ambulacral areas.—There is no anterior groove; the unpaired ambulacral area is marked by a line of tubercles along each edge. The intermediate space is covered by fine granules with a few smaller tubercles interspersed. The pores, only visible in worn specimens, are small and round and disposed in oblique pairs at comparatively great distances apart.



FIG. 5.—Part of one of the paired ambulacral areas of *E. Smellii*. $\times 6$.

The paired ambulacral areas (Fig. 5) are sub-petaloid and level with the test, the anterior pair being more divergent than the posterior pair. The plates are small and their length is three to four times their height. Each contains a pair of conjugate pores, set obliquely and both elongated, the exterior more so than the interior one. The pore-pairs are separated by a ridge bearing six to eight small granules along the upper edge of each plate. The number of pore-pairs in the anterior ambulacral pair is usually greater than that

in the posterior pair by one, two, three, or four pairs, according to the height of the individual, the higher individual having the greater difference. In a few specimens, however, the number of pore-pairs in the anterior and posterior ambulacral areas is the same. The space between the pore zones is very narrow and in a groove; its width is a little less than the length of the larger pore.

Interambulacral areas.—One plate corresponds to seven in the ambulacral area. Eight plates in a column can be counted above the ambitus. The tubercles, which are distributed unevenly over the areas, are largest and show rough alignment on the adambulacral parts. The intertubercular spaces are covered with small granules which form scrobicules round the tubercles (Fig. 6.) The number of tubercles increases towards the ambitus, and on the inferior surface they are very numerous and close together, except in the areas corresponding to the posterior ambulacra which are devoid of tubercles.

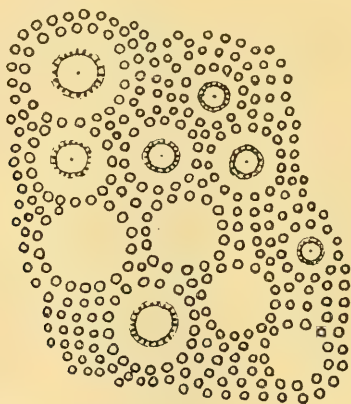


FIG. 6.—Arrangement of tubercles, magnified about twelve times, and showing areas where tubercles have been knocked off.

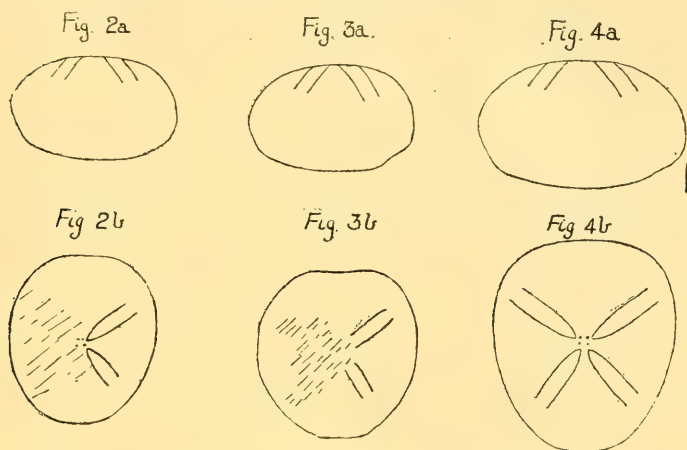
Dimensions.—The following are the dimensions of the specimens given as types in Figs. 1-4:—

LENGTH.	BREADTH.	HEIGHT.
mm.	mm.	mm.
39	37	29
29	26	18
29·5	28·5	19·5
36	32	22·5

The dimensions and the shape of these specimens seem very divergent for one species, but as they are exactly similar in other respects it is best to regard them as different varieties of the species.

This view is favoured by the fact that some specimens do not appear to belong to any of these types, but to an intermediate one.

An interesting point in connexion with *E. Smellii* is that several have, in the right anterior part of the test, a curious asymmetric bulge. In some it is very marked, in others it is hardly noticeable, and in others, again, it is absent. Since it is not diagnostic of the species, it is probably due to conditions of pressure under which the animal has been preserved. If so, it is remarkable that the right anterior portion of the test should be affected in every case. It is apparent to a slight extent in Figs. 2*b* and 3*b*.



FIGS. 2, 3, 4*a*.—Outlines of profiles of three other types of *E. Smellii*. Less than nat. size.

FIGS. 2, 3, 4*b*.—Outlines of same specimens from above. Less than nat. size.

Distribution.—Collected by Dr. Smellie from Senonian beds in the following localities: Shakarau, Warriz, Atash Gah, Anjir, Anerun, Pire Mahommed, Tang-i-Tima, Qayah, Kabir Kuh 1, 2, and 3.

Affinities.—*E. Smellii* differs from all others except *E. aquitanicus* d'Orbigny, 1853 (*Pal. franc. Terr. Cret.*, 6, p. 199, pl. 863), by the absence of an anterior sulcus. It shows a close resemblance to *E. aquitanicus*, but differs therefrom by having (1) the pores in the paired ambulacral areas set obliquely, (2) the granules in the ambulacral areas not extending to the median suture, (3) the pore-pairs in the unpaired ambulacra round, and further apart than in *E. aquitanicus*, (4) the largest tubercles on the adambulacral parts of the interambulacral areas and on the inferior surface.

21. *Iraniaster morgani* Cotteau & Gauthier, 1895 (op. cit., p. 28, pl. iv, figs. 1-12).

Localities.—Awasa (de Morgan). Shakarau, Warriz, Kabir-kuh 1, 2, and 3, Anjir, Pire Mahommed (Dr. Smellie).

Dimensions.

LENGTH.	BREADTH.	HEIGHT.	HEIGHT IN
			CENTIEME OF
mm.	mm.	mm.	LENGTH.
51·5	49	25·5	50
44	41	23·5	53
49	45	27	55
57·5	52·5	33	57
55	52	32	58
45	42	26	58

The height varies greatly. The more tumid specimens resemble in shape *I. Douvillei* (ibid., p. 30, pl. v, figs. 1-6), from which they are distinguished by having a more marked anterior groove and the fasciole nearer the ambitus.

22. *Hemiaster longus* Cotteau & Gauthier, 1895 (ibid., p. 40, pl. vii, figs. 1-5).

Localities.—Awâsa (de Morgan). In Dr. Smellie's collection the best preserved and most numerous specimens are from Shakarau; others from Warriz and Atash Gah are poorly preserved.

	LENGTH.	BREADTH.	HEIGHT.
	mm.	mm.	mm.
<i>Dimensions.</i>	17	14·5	10
	26·5	21	15
	31	24·5	17
	33	27	20
	42·5	33·5	26
	42·5	36	26·5

23. *Hemiaster noemiae* Cotteau & Gauthier, 1895 (ibid., p. 35, pl. vi, figs. 1-7).

Localities.—Awasa (de Morgan). Shakarau, Warriz, Atash Gah, Anjir, Kabir Kuh 1 and 2, Dahnah, Pire Mahommed, Tang-i-Nyaz (Dr. Smellie).

	LENGTH.	BREADTH.	HEIGHT.
	mm.	mm.	mm.
<i>Dimensions.</i>	13	12	9
	22·5	20·5	14·5
	26	24·5	19
	32	30	22·5
	34	31·5	25
	38·5	36	26·5

24. *Hemiaster morgani* Gauthier, 1902 (ibid., pt. iii, p. 131, pl. xix, figs. 3-4).

Localities.—Arkwase (de Morgan). Pire Mahommed (Dr. Smellie).

Dr. Smellie's specimen is distorted but is otherwise perfectly preserved. Its length is about 60 mm.

FIG. 1a.

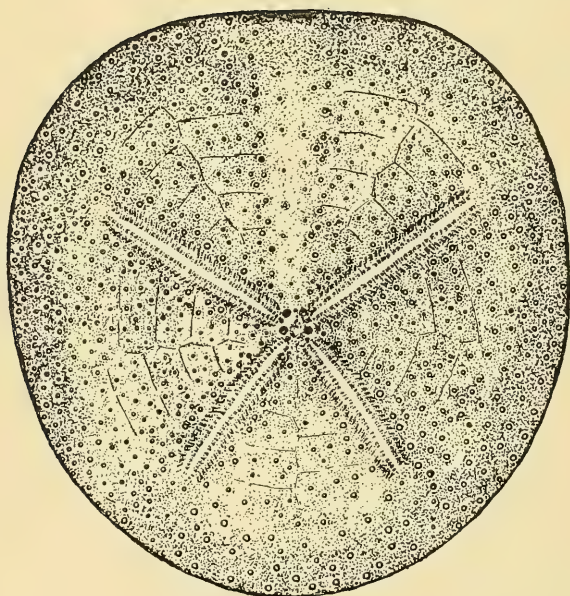
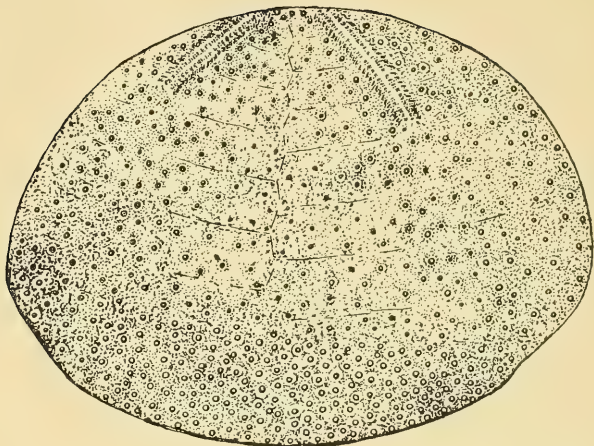


FIG. 1b.

EPIASTER SMELLII, n.sp.

The collection includes the following molluscs:—

Localities.

<i>Lopha dichotoma</i> Bayle.	Kabir Kuh 1, Warriz, Pire Mahommed, Shakarau.
<i>Lopha zeilleri</i> Bayle.	Pire Mahommed, Shakarau (along with <i>Ostrea</i> cf. <i>janus</i> Coquand).
<i>Lopha pectinata</i> (Lam.).	Kurac Kalul, Kabir Kuh 1, Warriz, Pire Mahommed.
<i>Lopha morgani</i> Douvillé (ibid., pt. iv, p. 275, pl. xxxvi, figs. 1-7).	Dere-i-Sahir (de Morgan). Anerun, Pire Mahommed.
<i>Lopha unguolata</i> (Schlotheim).	Kurac Kalul.
<i>Exogyra matheroni</i> (d'Orbigny).	Warriz, Pire Mahommed, Atash Gah, Anjir, Kurac Kalul, Dere-i-Sahir.
<i>Pseudoheligmus morgani</i> Douvillé (ibid., p. 264, pl. xxxv, figs. 3-5).	Dere-i-Sahir (de Morgan). Warriz, Tang-i-Nyaz, Dahnah.
<i>Spondylus subseratus</i> Douvillé (ibid., p. 268, pl. xxxv, figs. 8-14).	Awasa (de Morgan). Anjir (Dr. Smellie).
<i>Plicatula hirsuta</i> Coquand.	Warriz.
<i>Neithea tricostata</i> Bayle.	Atash Gah.
<i>Trigonia orientalis</i> Forbes.	Anjir.
<i>Gryphæa vesicularis</i> (Lam.).	Shakarau.

The collection also includes two species of brachiopods.

<i>Terebratula brossardi</i> Thom. et Pér.	Atash Gah.
<i>Terebratula toucasi</i> (d'Orbigny).	Warriz, Anjir, Pire Mahommed.

CONTRACTIONS.

<i>Contraction used.</i>	<i>Exact Locality.</i>
Kabir Kuh 1.	Kabir Kuh, west of Sar-ab-i-Maima.
Kabir Kuh 2.	Kabir Kuh, north of K.B. Point.
Kabir Kuh 3.	Base of Kabir Kuh, between Chashma-i-Kani Pahan and Arkwase.
Anjir.	Junction of Rivers Gulgul and Dalau, 4-5 miles north-west of Anjir Trigonometric Station.
Pire Mahommed.	Five miles west of Pire Mahommed on the road to Amirabad.
Warriz.	Four to five miles south and south-east of Deh Bala.
Anerun.	Valley north of Anerun.

EXPLANATION OF PLATE XI.

FIG. 1a.—Profile of a specimen of *E. Smellii*. Twice nat. size.

FIG. 1b.—View of same specimen from above. Twice nat. size.

I must acknowledge my indebtedness to the Carnegie Trust, who have furnished means for publication of the plate.

Some Remarkably Preserved Brachiopods from the Lower Magnesian Limestone of Durham.

By C. T. TRECHMANN, D.Sc., F.G.S.

(PLATE XII.)

SEVERAL quarries in the neighbourhood of Shildon, near Bishop Auckland in South Durham, display interesting sections of the Lower Magnesian Limestones and the beds on which they rest. At present the most instructive is that at East Thickley, near Shildon railway station, and as there seems a probability in the near future of this quarry becoming obscured by pit refuse, a record of the section exposed in it seems to be desirable. A large part of the rock-face has already been so obscured. A short distance south-east of this one other quarries exist closely adjoining the railway, but they are now almost entirely filled up with rubbish though sections in the railway cutting may still be seen. About a mile south-west of Thickley across the railway a quarry is at present being worked near Midderidge Grange, and seems to be the one in which important reptilian and other vertebrate remains were found in the Marl Slate many years ago. Notable among these is the headless skeleton of *Proterosaurus Huxleyi* Hancock & Howse,¹ each bone of which has the interior filled with galena. This and other important specimens are now in the Hancock Museum at Newcastle-on-Tyne. At present, however, the only rock visible in Midderidge Quarry is the dolomitic Lower Magnesian Limestone, in which no fossils are to be seen. These quarries are either, as in the case of East Thickley, situated on the junction of the Permian with the Coal Measures, or, in the case of Midderidge, very close to the junction.

Returning to East Thickley (Fig. 1), where about 45 feet of rock is exposed in the quarry face, we find that the lowest bed consists of sandstones of the Coal Measures between the Harvey & Brockwell seams. These are generally massive and current-bedded; about 12 feet of them are exposed and until a few years ago they were quarried as building stone. Above these come the Marl Slates, about 8 feet thick. At the base of the Marl Slate and resting on the Coal Measures there is an irregular bed a few inches thick of yellow dolomitic marl with sand and small rounded pebbles chiefly of quartz. It appears to fill up shallow depressions on the denuded surface of the Coal Measures and may, perhaps, be regarded as the equivalent of the Yellow Sands of the Permian, which are absent in this section. This pebbly bed is interesting as it contains numerous specimens of *Lingula credneri* Gein., the phosphatic shells of which are perfectly preserved even to the extent of retaining the different shades of colour on the bands of growth. Some of these *Lingula* valves are brown in colour, while others are bluish grey.

The overlying Marl Slate still yields fish and plant remains, or did

¹ *Q.J.G.S.*, vol. xxvi, 1870, p. 568.

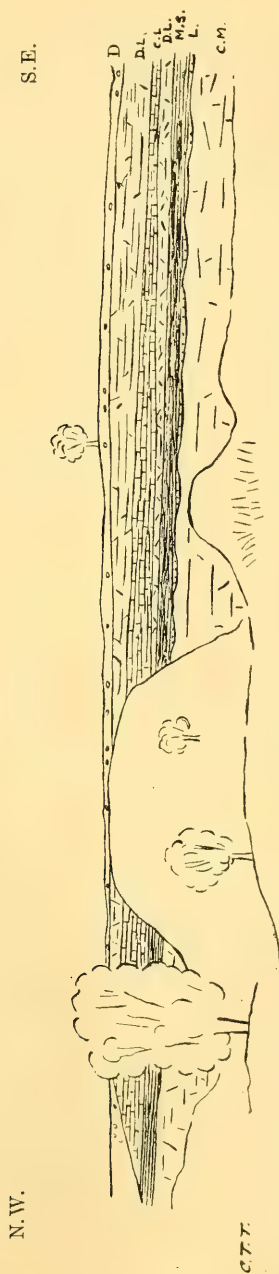


FIG. 1.—Diagrammatic sketch of the section in East Thickley Quarry, near Shildon, South Durham. Thickness of rock exposed about 45 feet. C.M., Coal Measures; L., Pebbly dolomite marl with *Lingulae*; M.S., Marl Slate; D.L., Dolomitic Lower Limestone; C.L., Fossiliferous calcareous Lower Limestone thinning out to the south-east; D., Glacial drift. Part of quarry obscured by refuse heaps and vegetation.

so plentifully until a few years ago while the underlying sandstone was being quarried.

Dr. Coggin Brown found here a specimen of the teeth and shagreen of *Janassa bituminosa* Schloth. some years ago when he and I were collecting in the Marl Slate at this place.

The Marl Slate passes up rather gradually into the compact dolomitic Lower Magnesian Limestone, and this in turn merges up into a bed of calcareous limestone, which is fairly thick in the north-west end of the quarry, but gradually thins out towards the south-east. This is again overlain near the top of the section by dolomitic rock very similar to that above the Marl Slate. The dolomitic rock appears to have been deposited as dolomite, and is only very sparsely fossiliferous, but the calcareous beds have yielded a very interesting suite of excellently preserved fossils, to some of which I wish to draw attention.

The calcareous Lower Magnesian Limestones, which consist of very pure limestone in South Durham, are of rather unusual interest, as they seem to occur as lenticular masses in the dolomite. In many Permian sections the whole of the Lower Limestone is dolomitic throughout, but in others the calcareous beds attain a considerable thickness.

At Raisby Hill Quarries, near Coxhoe, 9 miles north-east of Thickley, they are about 60 feet thick, but are much less fossiliferous than at Thickley. In a boring recently put down near Sheraton, in South Durham, 6 miles east of Coxhoe, the calcareous beds proved to be about 120 feet thick, but no fossils appeared in the cores.

I have nowhere seen the calcareous Lower Magnesian Limestone so fossiliferous as it is at East Thickley, and the rock appears on examination of weathered surfaces with a lens to be made up of organic fragments, though, strangely enough, a thin slice reveals practically no structure. I have already published analyses of these rocks.¹

Some remarkable blocks of limestone have recently been collected, the weathered surfaces of which, after being cleaned and developed, show something of the manner in which the Brachiopods lived, associated together on the bed of the Permian sea. Two of these seem to deserve special attention and illustration.

The first, represented by a sketch (Fig. 2), exhibits a specimen of *Productus horridus* Sow., bearing on one side two thick slightly curved spines which spring from the ear of the ventral valve and measure between $2\frac{1}{2}$ and 3 inches in length. Near the end of one spine (A) a specimen of *Epithyris elongata* Schloth., now rather crushed, has fixed itself by the foramen of its ventral valve, the back of which is visible on the slab. The oval outline, gently rounded surface, absence of median sinus and punctation of the shell in this

¹ "Lithology and Composition of Durham Magnesian Limestones": *Q.J.G.S.*, vol. lxx, 1914, p. 247.

specimen are noticeable. At the extremity of the other spine (b) a small *Strophalosia* has fixed itself by attaching its ventral beak and by winding the long, matted spines of its ventral valve around the *Productus* spine. The specimen shows the spines of the ventral valve, the area of both valves and the surface of the dorsal valve. The latter is nearly flat and is devoid of spines but the concentric lamellar growth-lines are well seen, together with the hinge teeth of the ventral and a median septum in the dorsal valve.

It does not closely resemble any of the specimens of *Strophalosia* illustrated by W. King in his Permian Monograph, pl. xii; these, however, are, with the exception of one from Whitley, from various localities in the Shell Limestone of the Middle Magnesian Limestone of Durham.

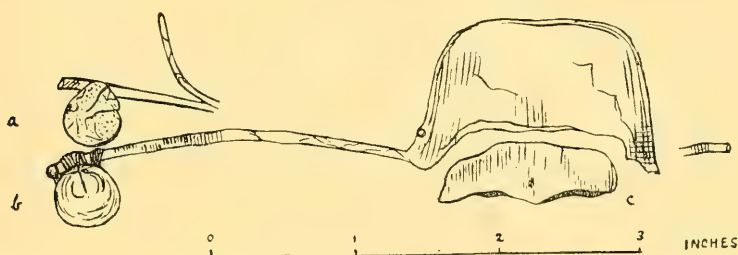


FIG. 2.—Sketch of a specimen of *Productus horridus* Sow., with long spines on the ventral valve. c, part of interior of the dorsal valve; a, a specimen of *Epithyris elongata* Schloth.; b, a specimen of *Strophalosia lamellosa* Gein.

Calcareous Lower Magnesian Limestone, East Thickley: Quarry, Durham.

Neither does it agree with any of T. Davidson's figures of English Permian specimens, illustrated in his monograph of Permian Brachiopoda, pl. iii. Turning to Geinitz,¹ however, one finds a species which he calls *S. lamellosa*, in which the dorsal valve is almost circular in outline, nearly flat, and free from spines. I have some specimens collected and labelled by the collector, Robert Eisel, of Gera, as belonging to this species, which very closely resemble the specimen under discussion. They are said to come from zone 3² of the Lower Zechstein, of Roschitz, Röspsen, near Gera, and are in a remarkably finely preserved testiferous state, as are the Thickley specimens also. The species *S. lamellosa* is questionably quoted by King as a synonym of his *S. Morrisiana*. Davidson figures several specimens all from the English Shell Limestone, and calls them *S. lamellosa* Gein., var. *Morrisiana* King, and var. *Humbletonensis* King. He discusses the matter further in a supplement to his

¹ *Der Dyas*, Leipzig, 1861, pl. xviii, figs. 1-7.

² These zones appear to be local divisions established in the Gera district. So far as I remember from conversation I had with R. Eisel in 1913 the zones of the lower Zechstein are characterized by different shape-variants of *Productus horridus*.

Permian Brachiopoda (p. 269), and expresses the opinion that all the known British Permian *Strophalosias* are referable to two species. He is, however, uncertain whether one is quite justified in placing King's *S. Morrisiana* among the synonyms of *S. lamellosa*. Geinitz (p. 98) is emphatic that *S. lamellosa* is a distinct species and I think most palæontologists nowadays would agree that this is so.

The second block of limestone¹ is illustrated nearly natural size by a photograph (Pl. XII). The most conspicuous fossil on it is *Productus horridus*, of which there are three examples, the largest, a ventral valve, measuring about 3 inches across, with spines nearly or quite 3 inches long. Another smaller specimen, of which the apical region of both valves is exposed, shows the long curved spines springing from the hinge line and surface of the dorsal or concave valve as well as from the hinge line of the ventral valve. Among the other fossils are some exceptionally large specimens of *Streptorhynchus pelargonatus*, Schloth. Near the top corner of the slab (B), the crushed specimens of two ventral valves of this brachiopod are seen together with the interior aspect of a dorsal valve. The sharp radial ribs are noticeable. They agree in size and all other respects with specimens I have from zone 3 of the Lower Zechstein of Roschitz, Röpsen, near Gera, and are very much larger than the dwarfed specimens that commonly occur in the lower parts of the Shell Limestone reef in Durham. A ventral valve of *Spirifer alata* Schloth. (c) is also visible.

Several *Strophalosias* occur on the slab, the most remarkable of which is that at (A). It is attached to the end of the long spines of two different *Producti*, the shell of one of which is broken away from the slab. The spines of its ventral valve are very numerous, massed together, directed backwards and twined round and about the *Productus* spines. The areas of both valves are visible; that of the ventral is rather high and concave. The dorsal valve is deeply concave and covered with massed spines much shorter than those of the ventral valve, and mostly directed inwards to the centre without, of course, being attached to anything. This specimen again resembles very closely indeed some examples of *Strophalosia goldfussi* Münster I have from Trebnitz, near Gera, belonging to zone 4 of the Lower Zechstein. I obtained these specimens also from Robert Eisel. Similar, but rather less well preserved, examples are illustrated by Geinitz in his *Dyas*, pl. xvii, fig. 21-24.

Geinitz remarks that this species as it appears in Germany does not seem to have been found in England, and he refers all the specimens hitherto described as *S. goldfussi* by English authors to *S. excavata* Gein. Another *Strophalosia* appears on the slab with its ventral apex apparently attached to the left ear of the large *Productus*, and shows only a poorly preserved concave dorsal valve which seems

¹ This specimen was found by Dr. Stanley Smith, F.G.S., during a recent visit by him and myself to Thickleby, and he kindly placed it at my disposal.



Surface of a block of Calcareous Lower Magnesian Limestone from East Thicketley Quarry, Durham, about $\frac{7}{8}$ natural size.

to belong to *S. Morrisiana* King, a species which is rather common at Thickley.

I shall not in this short note attempt to give a complete list of the rather numerous fossils that occur at Thickley, as I am preparing a synoptical table of the fauna of the chief fossiliferous horizons of the Durham Permian for a future paper. The difficult group of the Permian Strophalosias of England is one on which much might be written, including among them the curious small form called by King *S. parva*, which domiciles itself in the interior of empty valves of *Productus horridus* in the Shell Limestone reef. A sound revision of the Permian fauna is a task which would undoubtedly repay the effort expended on it.

EXPLANATION OF PLATE XII.

Surface of a block of Calcareous Lower Magnesian Limestone from East Thickley Quarry, Durham, about $\frac{2}{3}$ natural size. In middle *Productus horridus* Sow., with long spines. At A, a *Strophalosia goldfussi* Münst. attached to the *Productus* spines; BBB, specimens of *Streptorhynchus pelargonatus* Schloth.; C, specimen of *Spirifer alata* Schloth.

On the Rocks of the Avon Section, Clifton.

By SIDNEY H. REYNOLDS, M.A., Sc.D.

AN account of the lithological succession of the rocks of the Avon Gorge was given at the Bournemouth meeting of the British Association in 1919, and a summary of the rock-characters mainly from the lithological aspect was published in the GEOLOGICAL MAGAZINE (1919, p. 523). Further work has now been done, and a full account of the rocks is published in the current issue of the *Quarterly Journal of the Geological Society*.¹ The following summary prepared for the above paper was considered redundant owing to the fact that the matter it contains is already incorporated in the text of the paper. In view, however, of the importance and accessibility of the Avon Section it is thought that a brief statement such as the following, in which the rock-characters are summarized firstly from a stratigraphical and secondly from a lithological aspect may be useful.

I. DESCRIPTION OF THE ROCKS FROM THE STRATIGRAPHICAL ASPECT.

A. The Cleistopora Beds.

The Modiola Shales *K_m*.—The lower beds, which are ill-exposed, consist of sandy shales, of tencalcareous, and impure limestone. The upper beds consist of thin-bedded, often sandy, and rubbly limestones with reddish shaly partings. Small lamellibranchs, ostracods, and calcareous algæ are the most characteristic organisms. Small gastropods, brachiopods, and crinoids are also

¹ *Quart. Journ. Geol. Soc.*, vol. lxxvii, 1921, p. 213.

frequent and tubicolous annelids occur. The beds are of shallow-water character, and constitute the earliest *Modiola* phase of the Avon Section.

The Bryozoa Bed (horizon *a*) consists of massive ferruginous limestone, mainly composed of crinoids, but with very plentiful bryozoa at certain levels.

*K*₁.—Consists of shale and mudstone alternating with thin-bedded limestone. The principal limestone builders are crinoids and brachiopods. Ostracods and bryozoa are sometimes plentiful. In the "Palate Bed" at the base Elasmobranch teeth are abundant.

*K*₂.—Only the upper part of this horizon is well exposed, the rocks consisting of thin-bedded highly fossiliferous limestone alternating with shale. Crinoids and brachiopods are the principal limestone builders. Ostracods and bryozoa are plentiful at some levels. A little dolomitization has taken place in some of the highest beds.

B. *The Zaphrentis Beds.*

Horizon β.—On the right bank this horizon consists of rather massive limestone with crinoids and brachiopods. On the left bank the rock is thinner-bedded.

*Z*₁.—The lower beds are crinoidal and brachiopodal limestones overlain by thick-bedded dolomite, capped by a chert band. The upper beds are dark dolomitized crinoidal limestone (petit granite), with many fossils, especially brachiopods.

*Z*₂ and horizon *γ*.—Consists almost throughout of dark crinoidal limestone (petit granite). The matrix is almost everywhere completely dolomitized, but where this has not taken place foraminifera and *Calcisphaera* become for the first time plentiful. The larger fossils, particularly the crinoids, resist dolomitization and are the chief limestone builders. Brachiopods are less and corals more common than in *Z*₁. The "Fish Beds" at the top of *Z*₂ contain numerous Elasmobranch teeth and spines.

C. *The Syringothyris Beds.*

*C*₁. (*a*) *The Laminosa Dolomite*.—Consists of crinoidal limestone almost completely replaced by dolomite. At the top is the sub-oolite bed with abundant *Chonetes* and *Orthotetes*.

*C*₂ (*b*) *The Caninia Oolite*.—This is a fine-grained white oolite, the grains often enclosing foraminifera. Other fossils are scanty.

*C*₂. *The Caninia Dolomite*.—The lower beds are composed of grey and pale dolomite alternating with calcareous shale and mudstone occasionally algal. The dolomite was originally in the main oolitic or foraminiferal limestone. The upper beds are mainly china-stones with ostracods and calcareous algæ. The *Caninia* dolomite commences the second *Modiola* phase of the Avon Section.

D. The *Seminula* Beds.

S_1 continues the second *Modiola* phase of the Avon Section.

S_1 (a).—Mainly calcite mudstones with algal, ostracodal, and *Seminula* layers and a *Lithostrotion* (*Diphyphyllum*) band at the base. Overlying these beds are limestones with *Lithostrotion martini* and thick shaly partings.

S_1 (b).—Mainly dark, massive, much dolomitized limestones, with abundant *Lithostrotion martini*, but including shaly partings and some bands of china-stone type.

S_2 (a) *The Seminula pisolite and associated rocks*.—These consist of shallow-water deposits—calcite mudstones, dolomites, and pisolites associated with massive dolomitized *Lithostrotion* limestones. At the top are dolomites with three chert bands.

These rocks form the upper part of the second *Modiola* phase of the Avon Section.

S_2 (b) *The Seminula Oolite*.—The lower part consists of massive white fossiliferous oolite, the grains being often formed round foraminifera. The upper beds, in addition to oolites, include foraminiferal limestones.

S_2 (c).—The rocks of this level are chiefly massive foraminiferal limestones with *Chonetes* and *Lithostrotion* bands, and are often considerably dolomitized. The upper beds include china-stones and pisolites and commence the third and last *Modiola* phase of the Avon Section.

S_2 (d) *The "Concretionary Beds"*.—These consist largely of china-stones with bands of *Seminula* pisolite and more rarely oolitic layers, but their most marked feature is afforded by the numerous "Concretionary" (algal) bands.

E. The *Dibunophyllum* Beds.

D_1 .—The lower part consists of highly foraminiferal and coral-bearing white limestone associated with layers of coarse red oolite, and numerous bands of pseudobreccia. Thin shaly partings often separate the limestone bands. The upper part consists in the main of bands of coarse red oolite alternating with thick bands of shale and red grit.

D_2 .—Except for the fact that this horizon commences with a band of quartz conglomerate, the lithological types are identical with those in D_1 . The lower beds are chiefly grey foraminiferal limestones and pseudobreccias, in the middle part coarse red oolites prevail, while the upper beds include much red grit and shale.

II. DESCRIPTION OF THE ROCKS FROM THE LITHOLOGICAL ASPECT.

(a) *Calcareous Rocks*.

These may be classified according to the nature of their chief organic constituent:—

(1) *Algal Limestones* are abundant in all the rocks which accumulated under *Modiola* phase conditions, viz.: (a) in K_m ; (b) at the top of the *Caninia* dolomite, C_2 ; (c) in the lower part of S_1 ; (d) in the *Seminula* pisolite bands of the lower part of S_2 ; (e) in the Concretionary Beds of the upper part of S_2 . Calcareous algæ have also been met with in the lower part of C_2 and the middle part of S_2 .

Mitcheldeania is the most persistent form ranging from the extreme base of the section to the top of S_2 . *Ortonella* is characteristic of the K beds. *Solenopora* is found occasionally in the K beds. *Spongiostroma* associated with subordinate *Mitcheldeania* is prevalent in the calcite mudstones which are so abundant throughout C_2 and S. *Girvanella* tubules are seen forming the centre round which some of the oolitic grains in the lower part of D_1 have formed. *Aphralysia* was found in C_2 and S_2 (d).

The algal material commonly tends to form nodules, but in K_m it also occurs as narrow layers interbedded with gritty bands, and in S_1 the *Spongiostroma* masses tend to form undulating sheets. In S_2 , especially in the lowest beds, the *Seminula* pisolite type prevails, characterized by the *Spongiostroma* and sometimes *Mitcheldeania* layers being arranged concentrically, often round *Seminulæ*. Lastly the Concretionary Beds of the top of S_2 form the most important of the algal developments, *Mitcheldeania* being the prevalent form.

(2) *Foraminiferal Limestone*.—Foraminifera first begin to be fairly common in Z_2 . They are abundant in the *Caninia* oolite and are seen frequently in non-dolomitized bands (whether belonging to the calcite-mudstone series or to the oolites) in C_2 and the whole of S. They occur in great abundance in the white limestones of the upper part of S_2 , and the lower part of D_1 . They abound in the pseudobreccias. *Calcisphaera* first becomes plentiful in Z_2 .

(3) *Coral Limestone*.—Zaphrentid corals play an appreciable part as limestone builders throughout the *Zaphrentis* zone, and there is a well-marked *Caninia* band in S_1 . Bands full of *Lithostrotion martini* are most characteristic of the S beds, and there is a well-known band of basaltiform *Lithostrotion* in S_1 . The abundance of corals in the D beds is so familiar that it need not be emphasized.

(4) *Crinoidal Limestone*.—Crinoids occur in considerable abundance throughout practically the whole Lower Avonian, except in the *Modiola* shales and *Caninia* oolite, but are specially plentiful in (a) the Bryozoa Bed, (b) K_1 and K_2 , (c) the petit granite of the whole *Zaphrentis* zone. In the Upper Avonian crinoids are not specially characteristic, but occur in some abundance, and often reach a very large size in the white limestones of the D beds. Sections of echinid spines presumably to be attributed to *Palechinus*,

have been met with at various levels throughout practically the whole section from the lower part of K_1 to D_2 .

(5) *Brachiopod Limestone*. — Brachiopods associated with crinoids are very characteristic of K_1 and K_2 . They are abundant in horizon β and Z_1 , often forming well-marked bands in which *Spirifer clathratus* and *Chonetes hardrensis* are the most conspicuous forms. *Seminula*-bands are one of the most characteristic features of the S beds. *Productus* and *Chonetes papilionacea* bands are frequent throughout S and much of D. The suboolite bed (top of C_1) is also a strongly marked band of *Chonetes papilionacea*.

(6) *Bryozoa* occur abundantly in the Bryozoa Bed at the base of K_1 and in the upper part of K_2 , and are met with at various levels throughout the whole section.

(7) The presence of worms is often indicated where *Modiola* phase rocks are met with, thus small spirorbid annelids are common in K_m and C_2 . Tubular bodies probably due to worm borings are characteristic of the very white calcite-mudstones of S_1 and S_2 (a). Some of the shales of S_1 are full of "worm tubes".

(8) *Ostracods* are very plentiful wherever the rocks are shaly or of the calcite-mudstone type, viz. throughout K, at the top of C_2 , in the lower part of S_1 , and at certain levels in upper S_2 .

(9) *Molluscs* do not play an important part, though small lamellibranchs and small gastropods are plentiful in certain bands in K_m , and *Euomphalus* occurs sparingly in S_1 . Small gastropods seem characteristic of *Modiola* phase conditions, occurring in the calcite mudstones of S_1 as well as in K_m .

(10) Elasmobranch teeth and spines are very characteristic of the "Palate Bed" just above the Bryozoa Bed in K_1 , and of the "Fish beds" at the top of Z_2 .

Oolites occur at the following levels :—

(1) In the upper part of C_1 , the *Caninia* oolite.

(2) At the middle of S_2 , the *Seminula* oolite. Both these are very white rocks and of great thickness.

(3) Thin bands of oolite occur at various levels in the Concretionary Beds of S_2 and in C_2 .

(4) Thick bands of coarse red oolite occur at intervals throughout the D beds.

(b) Siliceous rocks.

Grits are met with only in the D beds (D_2 and upper part of D_1), where bands may reach a thickness of 20 feet. Sandy limestones are frequent in K_m and K_1 . Quartz grains occur frequently throughout the limestones of the C, S, and D beds, and at many levels secondary growth has converted them into doubly terminated crystals. In other cases the crystals seem to have been formed independently of pre-existing grains. Bands of chert due to the replacement of the limestone occur (a) near the middle of Z_1 , (b) just below the *Seminula* oolite, and (c) between the *Seminula* oolite and the Concretionary Beds. Partial silicification (beekite)

affects the fossils of upper K_2 , β , and Z_1 , and the Lithostrotiont corals, and occasionally the *Seminulæ* at many levels in the *Seminula* beds.

(c) *Argillaceous rocks.*

Thick shales are met with at three levels :—

- (1) Throughout the *Cleistopora* beds.
- (2) In the upper part of C_2 (*Caninia* dolomite) and in the lower part of S_1 .
- (3) In the upper part of D_1 and of D_2 .

Thin shaly partings occur in upper S_1 , in S_2 (c), and throughout the more calcareous parts of the D beds, where they are often associated with pseudobreccias.

REVIEWS.

DIE ERUPTIVGESTEINE DES KRISTIANIAGEBIETES. IV: DAS FENGEBIET IN TELEMAR, NORWEGEN. By W. C. BRØGGGER. Vid. Selsk. Skrifter I.M.N.Kl. No. 9, pp. 1-408. 1920.

IN a memoir of four hundred pages, furnished with nearly forty mineral and rock analyses, Professor Brøgger has added a fourth volume to his classic series on the eruptive rocks of the Kristiania region.

The Fen district of Telemarken forms a small isolated area of low relief of approximately 4 square kilometers extent, situated on the south-west shores of Lake Nordsjö, and surrounded on its landward borders by abruptly rising Precambrian granites. The area is best approached from Skien, by canal boat to Ulefos on Lake Nordsjö. The occurrence of iron ore and limestone in the Fen region had early attracted the attention of Vogt and other workers, but the unique significance of the area was not appreciated till the discovery by V. M. Goldschmidt in 1918 of microlite, alkali pyroxene, and hornblende, as constituents of the limestones. After this disclosure no further incentive was necessary for a more detailed investigation of the area, which Brøgger has completed in the present memoir.

The rocks comprised within the Fen area include a group of magmatic carbonate rocks, intimately associated with alkaline rocks showing a variable content of primary calcite. No less than thirteen new rock-types have been defined and described from this unique area. The characteristics of these new rock-types and their associated rocks may precede in description the geological history of the Fen region.

(1) *Vibetoite*.

This is the name given to the oldest intrusive of the silicate magma. It is a melanocratic, often coarse-grained rock, practically without felspar or nepheline, and consisting of hornblende, pyroxene, and biotite, and usually rich in apatite (3.51 per cent P_2O_5) and calcite (6.30 per cent CO_2).

(2) *Rocks of the Urtite-Ijolite-Melteigite series*.

These rocks form a continuous series, consisting essentially of nepheline and green pyroxene. The melanocratic member melteigite is a new type from the locality Melteig, and characterized as containing less than 45 per cent nepheline, associated with a green non-aluminous pyroxene (in part aegirine-diopside). True jacupirangite with an aluminous titanium-bearing pyroxene is not recorded in situ. A group of dyke rocks accompany this series, including micromelteigites, tinguaites, and melteigite-pegmatites.

(3) *Rocks of the Tveitåsite-Fenite series.*

These rocks form a probably continuous rock-series, consisting of green pyroxene and alkali-felspar (albite and microperthite). The melanocratic member is tveitåsite, and the leucocratic type is fenite. The fenites are accompanied by corresponding dyke rocks.

(4) *Nepheline-syenite-rocks.*

Quite sparingly distributed is a peculiar type of potash-rich nepheline-syenites, including the new type juvite (6.67 per cent Na_2O , and 8.21 per cent K_2O). This is a medium-grained rock consisting of orthoclase, pseudomorphs of muscovite and cancrinite after nepheline, aegirine, and sparingly biotite. A varietal type is described as biotite-juvite. The melanocratic malignite is also developed. The new rock-type kamperite may conveniently be included here. This rock consists essentially of orthoclase, albite, and biotite. It is a perpotassic type (10.16 per cent K_2O), and the analysis corresponds closely to that of the leucite-basalt of Gaussberg, Antarctica.

(5) *Carbonate-rich rocks.*

(a) *Sövite*.—A magmatic carbonate-rock consisting essentially of calcite, with apatite, microlite, biotite, and manganophyllite micas as important accessories.

(b) *Rauhaugite*.—A magnesium-rich carbonate-rock (MgCO_3 17.47 per cent, FeCO_3 9.60 per cent), associated with apatite, barite, and magnetite. In the normal rauhaugite, microlite and manganophyllite do not occur.

Apart from large masses of these types, independent dykes of sövite and rauhaugite are developed cutting fenite, etc. The rauhaugite dykes are apatite-rich dolomites (MgO 17 per cent, CaO 31 per cent, P_2O_5 2 per cent).

(c) *Mixed Rocks*.—Rocks which must be regarded as mixtures of carbonate magma of sövite type, and of the silicate rocks already enumerated are developed as schlieric intrusions, or as dykes cutting other members of the Fen group. These mixed rocks include hollaite and kåsenite, considered as crystallized products of a mixture of calcite magma and ijolite-melteigite magma, the former relatively rich in silicates (pyroxene, nepheline pseudomorphs, melanite, etc.), and the latter with a relatively small content of silicate minerals; further, ringite, a type resulting from a mixture of calcite magma with a fenite magma constituted of calcite, felspar, aegirine and aegirine-diopside, and apatite.

(6) *Damkjernite-sannaite rocks*

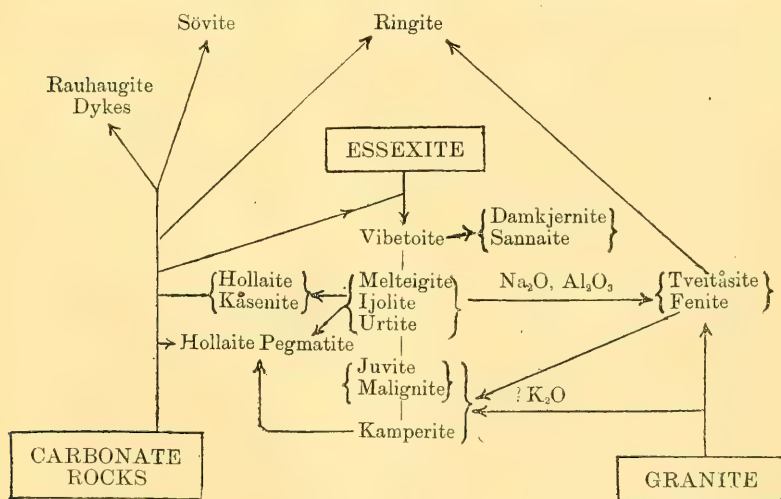
An alnöite-like rock which Brøgger regards as the latest product in the intrusive sequence of the Fen region is described as damkjernite. These rocks are melanocratic members of the alnöite group, and show some variety in composition. The normal type contains large phenocrysts of black biotite, and less commonly

pyroxene, set in a ground mass of pyroxene, apatite, biotite, magnetite, orthoclase, and a small amount of nepheline pseudomorphs. An exceptional type is present as a dyke rock in the Precambrian granite, and contains large barkevikitic hornblende individuals, and nodules of olivine-enstatite, enstatite-diopside, hornblende, etc., as endogenous inclusions.

Sannaite, which fills an explosion crater at Ormen, 7 kilometers south-west of the Fen region, is a closely related type, forming the end member of the damkjernite-sannaite group. It differs only by the presence of a higher content of alkali minerals. The phenocrysts are of brown-black hornblende, black pyroxene, and sparing biotite in a fine-grained ground mass of alkali-felspar, aegirine, and, in smaller amount, of nepheline pseudomorphs (muscovite).

(7) The latest eruptive rocks of the Fen area are the diabase dykes of post-Silurian date, and which are so constant a feature in the Kristiania region.

The geological history of the Fen region as pictured by Brøgger may now be shortly summarized, the probable genetic relations of the Fen sequence being indicated in the following scheme.



The opening phase in the Fen history was the drilling of an explosion crater in the Precambrian granite. The initial magma was of basic composition, and probably of essexitic type, confirmation of which is provided by the great dominance of the melanocratic melteigite, and also by the interpretation of the oldest vibetoite as an addition product of a calcite magma and a magma of yamaskitic composition (hypermelanocratic differentiation-product of an essexite magma).

The melteigite of the Fen region can, as Brøgger shows, be considered as derived from an essexite magma by admixture with calcite, with removal of certain percentages of anorthite and iron-rich pyroxene, and, further, CO_2 , the former by gravitational sinking of crystals; the more leucocratic types, ijolite and urtite, by further sinking of the denser pyroxene.

The ultimate origin of the great mass of carbonate rocks of the Fen region raises a question of great difficulty. The complete resemblance, chemically and petrographically to the undoubted primary dykes of sövite, lead Brøgger to the conclusion that it must be regarded as a primary magmatic rock. Its ultimate source must be a sedimentary limestone which has been completely melted at great depth. By its purity and comparative poorness in silicates, it is sharply distinguished from the variable calcareous sediments of Palæozoic age in the Kristiania district. Still less does the rauhaugite bear resemblance to these, for dolomites are unknown amongst the carbonate rocks of the Kristiania region. Brøgger is of the opinion that the carbonate rocks must be derived by melting (solution) of an *older* limestone *below* the Precambrian granite.

After its melting at great depth, and separation from the carbonate-enriched stem-magma, the great central mass of carbonatite is pictured as forming a lighter layer floating on the heavy silicate magma. Its intrusion into the crater-neck of the Fen led to its crystallization from above downwards. The solid carbonate rock thus formed was penetrated in its outer part by the silicate magma, giving rise to the vibetoite and melteigite-ijolite intrusions. Pneumatolytic addition of phosphorus, fluorine, niobium, and tantalum occurred before consolidation, giving rise to apatite, and microlite in the resulting sövite. On its under side intimate mixtures of silicate magma and carbonate magma were formed, and gave schlieric intrusions of hollaite and käsenite.

The melteigite-ijolite magma has produced an intensive contact-metasomatism in the peripheral Precambrian granite. By the action of solutions an important transfer of soda has taken place. The quartz of the granite is replaced by albite, and the biotite by aegirine, oligoclase is converted to albite, and orthoclase into microperthite and albite, until, at the immediate border, the rock is completely transformed to an alkali felspar-aegirine rock—fenite, or its more melanocratic type, tveitåsite. All possible gradations from unchanged granite to the end product fenite can be traced.

That a transition from granite to aegirine-syenite by in situ differentiation is not involved, seems clear from the fact that the destruction of biotite with new-formed needles of aegirine and alkali-hornblende and the development of typical "Schachbrett Albit", so characteristic of secondary felspar, can be traced in thin sections of the transition rocks. Moreover, in intermediate stages some newly formed quartz appears, showing inclusions of aegirine. This quartz, unlike that of the granite, is completely free from

undulose extinction. Fenite also occurs as independent dykes, derived by direct melting (or solution) of granite in melteigite-ijolite magma. These penetrate the melteigite group, and have a typical pulaskitic structure. At the border between the fenite and melteigite group are quite locally developed the juvites and malignites. These are possibly derived from a mixture of fenite and ijolite magmas. Their high content of potash is perhaps to be explained as a direct transfer of potash solutions from the fenitized granite, a process complementary to fenitization itself.

Only in the small sack-shaped area in the vicinity of Melteig are the rocks of the melteigite-ijolite group completely fresh. Elsewhere they are completely or partially changed to muscovite-biotite (chlorite)-calcite-fels. It is probable that the potash absorbed in muscovitization of the already crystallized melteigites is also in part derived from the Precambrian granite.

Whilst the rauhaugite dykes which penetrate the fenite near Ringsevja must be regarded as primary, Brøgger is of opinion that the great eastern mass of rauhaugite is metasomatically derived from sövite. The source of the magnesia and iron, if this be so, must be the rocks of the melteigite group, from the destruction of pyroxene in their conversion to muscovite-chlorite-calcite-fels. Furthermore, this metasomatism must have occurred before the intrusion of the damkjærnites, for these contain in places xenoliths of the typical rauhaugite.

Against this view of Brøgger must be placed the fact that the normal rauhaugite does not contain either manganophyllite or microlite. The absence of the latter highly insoluble mineral is significant, and may point to the rauhaugite as an independent intrusion, or, if secondarily changed, a derivative of the magma which gave rise to the primary rauhaugite dykes.

At the conclusion of the fenite formation, and possibly its dyke intrusions, the carbonate magma in part retained its fluidity in depth, and was then erupted, partly as dykes of sövite, and less numerous dykes of rauhaugite, and partly as mixed magmas, as ringite, ringite-pegmatite, hollaite-pegmatite, etc. These latter pegmatites often show characteristic intergrowths of their constituent minerals, e.g. calcite and pyroxene.

Significantly younger than the above rocks and representing the last stages in the intrusive sequence are the damkjærnite intrusions which appear as dykes in the granite, in the fenite, in the melteigite group, and in the central carbonatite. Some of the damkjærnites contain inclusions of these rocks as well as fragments of older granite and amphibolite. The damkjærnites, as well as the sannaite, are late differentiation products of the melteigite group, and show a clear relationship with the earliest intrusive vibetoites. Their resemblance to the African and Brazilian kimberlites has led to a careful search for diamond, but without success.

As to the epoch of intrusion of the Fen rock series, Brøgger was

at first inclined to regard it as an outpost of the Devonian eruptives of the Kristiania region, but later he has come to consider it as of late Precambrian date, in common with the very closely analogous Alnö alkaline area (? Precambrian). The possibility of a Devonian age cannot, however, be wholly excluded. The assumption of selective solution in depth by a Devonian essexite magma, in the presence of mineralizers, of the calcite of an *overlying* impure calcareous terrane of Palæozoic date, seems here not to be entirely precluded. Whatever be the case, one of the most remarkable and so far inexplicable facts, is the absence of typical contact-minerals in the carbonatite.

The last chapter of the memoir is devoted to a critical comparison with the related rock sequences of Alnö, Almunge, Assynt, and other districts. Into this, and into Brøgger's highly interesting discussion of the distribution of Scandinavian alkaline areas with regard to orogenic axes of folding, it is impossible to enter here. Rocks of the Fen region can be matched in all the above-named alkaline fields, but in the Alnö assemblage, with its metasomatised (finitised) border-zone, the most marked resemblance is provided.

The great work is dedicated "in old friendship" to the investigators of Alnö, the Kola Peninsula, and Magnet Cove—Högbom, Ramsay, and Washington.

C. E. TILLEY.

TUNGSTEN ORES. By R. H. RASTALL & W. H. WILCOCKSON.
Imperial Institute Monographs, pp. ix + 81. 1920. Price
3s. 6d. net.

THE world depression in trade has sensibly reduced the consumption of ferro-alloys and brought about a heavy fall in the selling price. The interest in this and similar publications is necessarily somewhat limited at the present time. High-speed steel, in which tungsten is an essential constituent, was largely over-produced at the conclusion of the war period, and is still a drug in the market, so that economic conditions are not likely to improve for some time.

The monograph has been compiled from sources indicated in the bibliography included in the volume. It is well compiled, and presents in an abbreviated form the salient features of all the published material on the subject, and should be useful for reference, particularly by those commercially interested in the metal.

Tungsten was one of the metals controlled by Germany before the war, largely in consequence of an indisposition in this country to tackle the problem of the metallurgical treatment of the raw material; and this, notwithstanding that a large proportion of the tungsten mineral is produced within the Empire, and the manufacture of high-speed steel is one of our principal industries. Stern necessity compelled us to evolve processes for production of metallic and ferro-tungsten, and it is hoped that the impetus given by remunerative

war conditions will prevent the industry reverting to Germany, although it may be noted that at the present time that country is the only persistent buyer of tungsten ore. The value of the raw material was 25s. to 35s. per unit in 1914, but these figures were increased in this country during the war, and more particularly in the United States. So severe, however, is the slump that ore is now worth only 12s. 6d. per unit c.i.f. U.K. ports, and unless an appreciable rise takes place in the selling price, the cost of production will require severe readjustment.

In dealing with the genesis of tungsten ore, it is noted that they are usually found with tin in granite veins and pegmatites, and much controversy has arisen with regard to the relative temperature of formation of the minerals of these two metals, with a view to determine their occurrence in depth, in Burma and the Malay Peninsula. The authors remark that further information about other occurrences is desirable.

The sporadic occurrence of the mineral prevents any calculations of reserves being made, but its association with granitic rocks in many widely distant areas should guarantee a constantly increasing output, to meet the greater demands which will follow a general trade resumption, by reason of the valuable properties tungsten confers alone, and associated with other metals, on steel.

The remarks on the utilization of tungsten are useful. Whilst Mushet was undoubtedly the first to produce a special tool steel containing tungsten, the term "high-speed steel" was originally applied to a tungsten steel containing molybdenum, first exhibited in 1900. Subsequently British manufacturers made an equally good steel without molybdenum, but in recent years it, and other metals, have been introduced, and changes are made from time to time in the composition and heat treatment of the material in order to obtain the best results.

The use of tungsten for electric lamps is mentioned, and it may be remarked that the production of the wire was impossible, until a process was evolved whereby the ingot was heated in hydrogen to a point below annealing temperature, and subjected to repeated swaging, the effect of which was to elongate the equiaxial grains into fibres of metallic tungsten. In this way tungsten wire was made ductile by a method which usually produced brittleness in other metals. A small quantity of thorium nitrate, added to the tungsten oxide before reduction controls the grain growth, and by coating tungsten with a precious metal or alloy, the product has been found superior to platinum or its alloys in many ways.

The memoir is divided into three chapters, of which the first deals with the occurrence, characters, and uses of the ores, and the second and third with the British and Foreign sources of supply.

The description of occurrences of tungsten ores in the British Empire is good, although possibly greater prominence might have been given to the Burma deposits, having regard to the fact that

they constitute the principal source of British supply, and also because they have been examined and described by competent observers.

The frantic effort during the war to increase output, and/or obtain large profits must have resulted in Burma, as elsewhere, in bad development work and waste, more particularly as the greater part of the output was obtained from alluvial deposits and decomposed ground, worked by sluicing methods. With the return of normal conditions, more reasonable methods of operation will be instituted, and Government control, necessary in such conditions, be made more severe. The description of the Australian deposits is complete, although the output from them is relatively small.

Amongst foreign countries the largest supply comes from the United States, but China and Japan and the South American States and Portugal also produce appreciable quantities.

The fall in the value of the raw material has brought about almost total cessation of work everywhere, and it will be interesting to see from which deposit the mineral can be obtained at the lowest figure, to meet the changed economic conditions of the future.

H. K. SCOTT.

A SHORT ACCOUNT OF THE GEOLOGY OF THE ISLE OF WIGHT. By H. J. OSBORNE WHITE, F.G.S. *Memoirs of the Geological Survey*, pp. 219. With 1 Plate (coloured map), and 43 figs. London, 1921. Price 10s. net (paper covers).

THE Isle of Wight, on account of its varied structure, its fine coast sections, and its abundant fossils, has always been a favourite subject for study by those interested in geology, and it has now been investigated by at least four generations of scientific men. The results of such study were first brought together in Bristow's memoir, published in 1862, and revised by Mr. Clement Reid and Sir Aubrey Strahan in a second edition issued in 1889, but this work is now out of print. The present guide is intended to replace it, at least in part, and it gives a condensed but admirably presented account of what is now known upon the subject. It is written by one who on account of a long residence in the Island and an intimate acquaintance with its geological features is exceptionally well qualified for the task which was entrusted to him by the Geological Survey.

After a short chapter on the main physical features, and containing a table of the formations, the author describes in order the stratigraphical series beginning with the Wealden and passing upwards to the Hamstead beds of the Oligocene. The section on the Chalk has been much amplified as compared with that in the earlier Memoir, and it contains several new diagrams and sketches of coast exposures. The account of the stratigraphy is followed by a chapter on the tectonic structure of the Island and the post-Oligocene disturbances to which it has been subjected, and here

also a good deal of new matter is included. Not the least interesting part of the book is that dealing with the ancient river systems, and describing how the rivers arising in the south have had their valleys truncated by coast erosion, which is still going on, as may be seen by any visitor to Freshwater Bay and other places on the southern shore. It is shown, for example, how the Western Yar, which now opens into the Solent by a mouth disproportionately large for the size of the river, and rises a few yards from the sea at Freshwater Gate, once had a course extending eastward past Brook and Brighstone (here written Brixton) on the south of the chalk downs and as far as Blackgang and Atherfield, as is demonstrated by the gravels and brickearths exposed in the sections of the cliffs. These and other formations are well described in the chapter on superficial deposits. It is followed by a section on the economic geology, containing further new material, with good accounts of the different soils, of the building materials (and notably that supplied by the Bembridge limestone), of the road metal, the scanty fuel supplied by the brown coal-seams of the Bracklesham beds and the peat on Wroxall Down, and the phosphatic concretions and other minerals collected in small quantity in various parts of the island. The volume concludes with a chapter on the water supply. As already indicated the work is based on the Survey Memoir of 1889, but it is enriched by original observations by the author. It is intended to accompany the large-scale colour-printed map also issued by the Survey, for the map forming the frontispiece is inadequate, and compares very unfavourably with that which appeared in the earlier Memoir. The omission of the figures of the characteristic fossils is to be regretted in a work intended mainly to be popular. The tables of fossils and the other appendices to the former Memoir are likewise excluded, but this may be regarded as inevitable in view of the small compass of the book, the present volume containing 219 pages, as against 349 pages to the Memoir of 1889. Nevertheless, the price of Mr. Osborne White's memoir is 10s., while that of the earlier and larger volume was 8s. 6d. This is a matter for regret, since a reliable and comprehensive book, such as Mr. White's work undoubtedly is, if sold at a more moderate price would almost certainly command a large sale among the visitors to the island.

F. H. A. M.

REPORTS AND PROCEEDINGS.

MINERALOGICAL SOCIETY.

1st November, 1921. — Dr. A. Hutchinson, President, in the chair.

Professor H. Hilton : On the determination of the optic axes of a crystal from extinction-angles.

The problem of obtaining the positions of the optic axes of a crystal from the extinction-directions on four known faces was discussed,

and it was shown from a purely geometrical standpoint that the solution is unique. Their position was also found graphically as the intersection in the gnomonic projection of two cubic curves, on which any number of points can be obtained by the use of the ruler only.

W. Campbell Smith : On some minerals from Leadhills.

Caledonite of pale-blue colour and acicular habit has been frequently described in the past as aurichalcite. Examination of all available specimens of so-called aurichalcite from this locality showed that all were caledonite of this acicular habit. The optical properties were found to agree with those of caledonite of the normal habit. It was shown that in caledonite the plane of the optic axes is parallel to (010) and the acute bisectrix is perpendicular to (100), and not as stated in Dana and other textbooks. Other remarks referred to gold, linarite, minium, and the rare mineral eosite.

Dr. J. Drugman : An example of porphyry-quartz from the Esterel Mountains (France) twinned on the face (1012).

This twin-law in quartz has previously been observed only by Q. Sella in 1858 and has been regarded as doubtful. An example of it has been found amongst the porphyritic crystals in the "blue porphyry" of the Esterel Mountains. A distinction is made between the twins of low-temperature rhombohedral α -quartz and those of hexagonal β -quartz (stable at a temperature above 575° C.).

Dr. L. J. Spencer : Biographical notices of mineralogists recently deceased ; with an index of those previously published in the *Mineralogical Magazine*.

EDINBURGH GEOLOGICAL SOCIETY.

19th October, 1921.—Mr. T. Cuthbert Day, F.R.S.E., F.G.S., President, in the chair.

"The History and Development of the Yorkshire, Derbyshire, and Nottinghamshire Coalfield." By Dr. Walcot Gibson, F.G.S., Assistant to the Director for Scotland, H.M. Geological Survey.

The lecturer pointed out that the area beneath which coal under a depth of 4,000 feet is considered as proved, amounted to 2,136 square miles, containing an actual coal reserve of over 41 thousand millions of tons. Many of the valuable seams lie under 3,000 feet depth, and there is a considerable area falling within the depth of 2,500 feet.

Dr. Gibson showed that the sequence was common to all the coal-fields of the Midland area, roughly estimated at 8,000 square miles, even to the persistence of individual seams of coal and thin beds of shale containing a characteristic marine fauna. Only a partial resemblance can be instituted with the northern group of coal-fields—including Scotland—or with those of the south and south-west of England.

Special points arising from the examination of the Midland sequence and of general significance are : (1) The existence of a floral break between the Upper and Lower Carboniferous rocks in North

Staffordshire; (2) the incoming of marine conditions in the Millstone Grits as they are traced northwards; (3) the possible correlation of the Alton (Ganister) Coal and its marine roof with the Slatyband Ironstone of Scotland, a correlation adopted by Hull; (4) the probable Lanarkian age of the measures below the Kilburn Coal of North Derbyshire; (5) the many marine bands containing Productids in the Westphalian (Middle) Coal Measures of the Midland Province; (6) a considerable thickness of barren measures not infrequently of a red colour, high up in the Westphalian Coal Measures, but below the Staffordian Coal Measures, and their possible correlation with the barren red measures of Fife and Midlothian; (7) the not infrequent occurrence of a marine bed resting directly on a seam of coal and the persistence of such seams of coal even when a few inches in thickness.

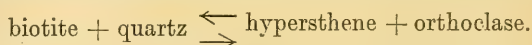
CORRESPONDENCE.

THE MAGNESIAN GROUP OF IGNEOUS ROCKS.

SIR,—The interesting paper appearing in your November number under the title: "The Magnesian Group of Igneous Rocks," raises a number of points which seem to require some further discussion. It is to a few of these only that I wish to refer here. The application of the term "magnesian" to a group of igneous rocks, the ultrabasic members of which alone show notable content of MgO , is an innovation that appears scarcely justified. In the intermediate and acid types it is iron and not magnesium which calls for note. The peculiar properties of this group of rocks are of a provincial order in a petrographic sense, and serve to rank the group as a distinct unit of the calc-alkaline suite, rather than a group co-ordinate with this suite. Amongst the "magnesian" provinces listed by Mr. Dixey there are some whose inclusion requires some further word of explanation. Number 7, in particular, finds itself among strange companions. Some of the characteristics of these rocks are explicable on the assumption of a low active mass of water in the magma, combined in certain cases with high pressure during consolidation.

A low magmatic water content may lead to an early precipitation of potash felspar, and we may note that orthoclase or microperthite is a not uncommon feature in the basic types, as in the Norwegian norites and the basic members of the Eyre Peninsula group. It is to this early precipitation of potash felspar that the occurrence of oligoclase or andesine as the plagioclase constituent of the microperthite in the basic types is due. This feature is best exemplified in the rocks of Western Norway. The occurrence of hypersthene in the intermediate and acid types is probably explicable on these lines. In the absence of abundant water the degradation of the metasilicate molecule to the orthosilicate type is inhibited, so

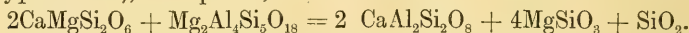
that hypersthene appears instead of biotite, as in the equation



The presence of garnet (almandine) in the more acid types at least, is also an expression of a low active mass of water to which may be added the influence of high pressure (*Q.J.G.S.*, 1921, p. 94). While the occurrence of hypersthene in acid charnockitic rocks may thus be ascribed to a comparative poorness in magmatic water, it is of interest to note that hypersthene is also found in acid rocks which otherwise cannot be included in this group. In such abnormal cases its presence can be ascribed to hybridism. This is the case with certain acid gneisses in the island of Rum, described by Dr. Harker. The conversion of olivine to enstatite (hypersthene) supplies an explanation in some cases where olivine is a constituent of the absorbed material. The monoclinic pyroxene of acid igneous rocks is characteristically a non-aluminous type, and it is not improbable that an aluminous type is unstable in the presence of quartz. Where acid rocks have been contaminated with basic material such as gabbro, the aluminous pyroxene of the latter might be expected to react with silica as in the equation :—



with the production of cordierite. But, as is well known, in contact metamorphism cordierite and diopside are mutually exclusive, and the products of this reaction under hydrostatic conditions would probably react with the production of anorthite, enstatite (hypersthene), and quartz, thus :—



Cordierite, being a common product of thermal metamorphism, it might be expected that hypersthene would similarly arise if diopside were present in the invading magma, by assimilation of aluminous sedimentary material. In this modified sense there may be some justification for Dr. J. W. Evans' contention, mentioned by Mr. Dixey, when applied to cases where hybridism can be proved on other grounds. It is of interest to note in this connexion the example afforded by the norite intrusions of Huntly, Aberdeenshire, described by Mr. W. R. Watt (*Q.J.G.S.*, 1914, p. 266). Monoclinic pyroxene is a normal constituent of the norite, but where the latter has been subject to contact metamorphism or has intruded sediments with transference of material, cordierite appears, but diopside is conspicuous by its absence.

C. E. TILLEY.

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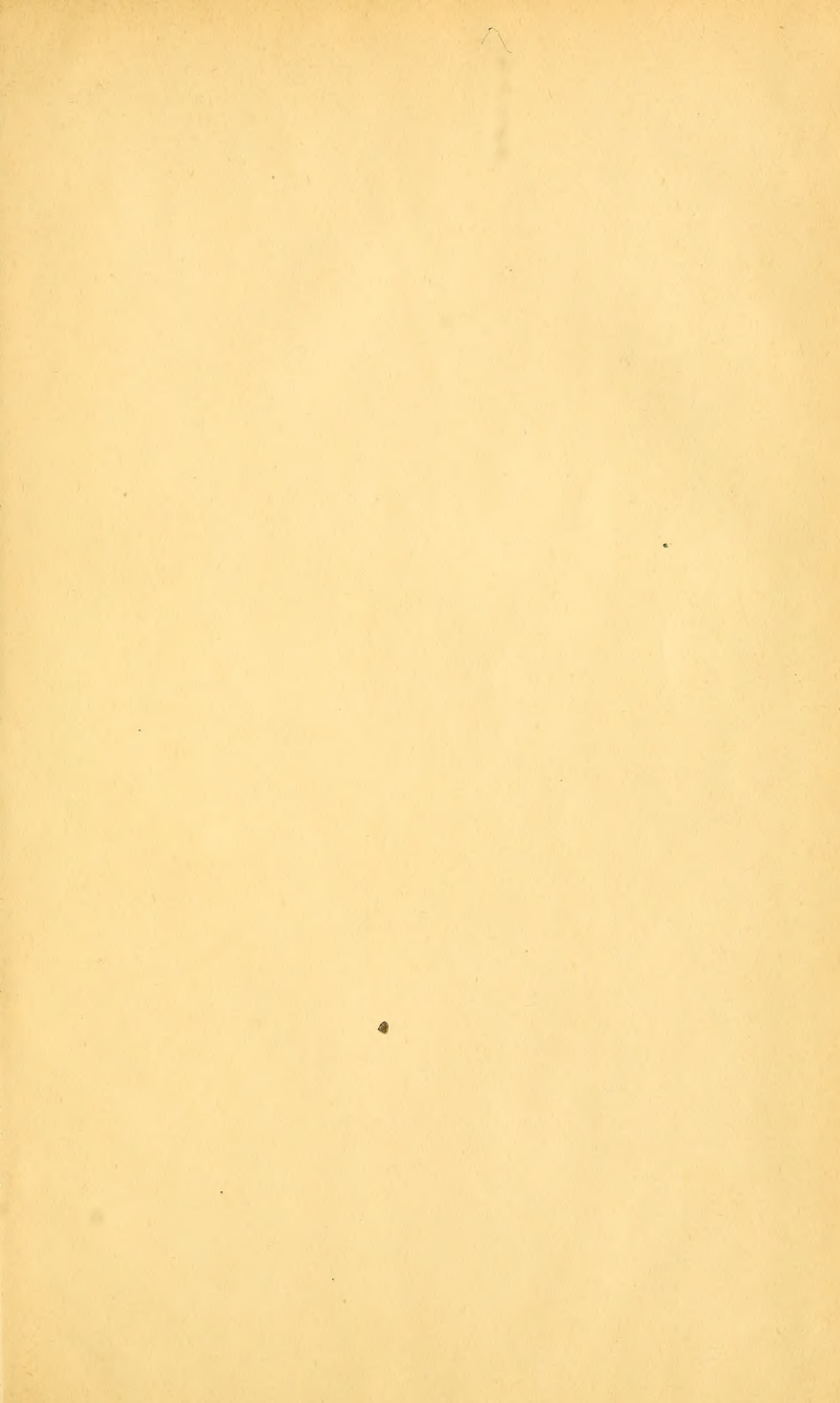
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